Macroinvertebrate Assemblages of the San Joaquin River Watershed

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Executive Summary

The San Joaquin River drains the mid-portion of the Central Valley of California, flowing north into the Sacramento-San Joaquin Delta that, in turn, discharges into San Francisco Bay. Most waterways in the lower San Joaquin watershed are dominated by agriculture. Many agricultural activities have altered (or have the potential to impact) physical, hydrological, and water quality condition in these waterways.

The Central Valley Regional Water Quality Control Board funded an exploratory project with UCD ATL that was designed to assess benthic macroinvertebrate (BMI) community structure and habitat conditions in a variety of agriculture- (ADW) and effluent-dominated waterways in the lower San Joaquin River and the lower Sacramento River watersheds. The current study deals with the data from the San Joaquin River watershed, while the Sacramento River bioassessment data has been published in a companion study (deVlaming *et al*., 2004).

One goal of both bioassessment investigations was to determine utility of the BMI bioassessment approach in assessing condition of Central Valley waterways. Very little is known regarding biological condition in ADWs of the Central Valley. Thus, another primary objective of both studies was to examine the nature and variability of BMI communities in ADWs of the lower Sacramento and San Joaquin River Basins as well as physical habitat and water quality parameters that potentially determine BMI community integrity. ADWs occur in the valley floor region, and can be natural, modified natural, and/or constructed waterways. The health of aquatic communities in ADWs can be impaired by physical habitat destruction or modification, hydrology regimes (e.g., modified and intermittent flow), sediment, elevated nutrients, contaminants (e.g., organic chemicals, including pesticides, other agricultural chemicals, and inorganic chemicals) and organic wastes.

BMIs constitute an important link in the food webs of freshwater aquatic ecosystems. Resident BMI communities of the heavily managed aquatic ecosystem of the Central Valley are, however, poorly understood. BMI community health varies in response to a variety of stressors that affect physical habitat and water quality. Bioassessments provide indications of aquatic system 'biotic integrity' as well as physical habitat condition/quality. BMIs are considered effective indicators of aquatic system biotic integrity and health.

The San Joaquin River (SJR) watershed bioassessment was conducted in spring and fall 2001. Fall and spring BMI samples were collected from downstream reaches within each sub-basin. Most of the ADW sites were low gradient (slope < 0.2) occurring within the valley floor region. Low gradient versions of the California Stream Bioassessment Protocol (CSBP) were used in the collection of macroinvertebrates. Simultaneously, physical habitat and land use data were collected. Traditional water quality data, including metals and nutrients, were collected monthly at most sites throughout the duration of the bioassessment study.

Physical habitat conditions in ADWs of the lower SJR were rated as marginal to sub-optimal. Streambeds were dominated by heavy deposits of fine material (considered poor BMI habitat), a high level of physical channel alteration, lack of channel sinuosity, unstable banks, little to no vegetative bank protection, and little to no riparian zones.

Composition and health of BMI communities varied considerably among SJR ADW sites. Sites on the Cosumnes River and upper Orestimba Creek, above most agricultural land use, were taxonomically different, and manifested a higher-level biological condition, compared to sites with greater agricultural influences. Further, even among sites surrounded by intense agriculture some sites were characterized by more extreme BMI community degradation than others. Sites ranged from those consisting mostly of oligochaetes (indicative of degraded condition) to those characterized by large populations of amphipods and dipterans, as well as some Ephemeroptera (mayflies), Trichoptera (caddisflies), and Odonata (damselflies and dragonflies). Sites with greater agricultural influences differed from one another in BMI metrics (community health) during both the June and September sampling events. BMI communities at sites within the same SJR sub-basins were not similar to one another, and BMI communities at sites in eastern sub-basins were not particularly different than those in western sub-basins.

Analyses revealed that metal concentrations (copper, lead, and zinc), riparian zone quality, total organic carbon (TOC) concentrations, total nitrogen concentrations, and level of organic wastes differentiated the agricultural-influenced sites from one another (i.e., were probable determinants of BMI communities and biological condition). Sites characterized by lower metal, TOC, and nitrogen concentrations, and possessing more intact riparian zones, consisted of more diverse BMI communities. Sites on Ingram Creek, Mountain House Creek, and TID 5 (Harding Drain), which were characterized by the highest metal concentrations and the poorest riparian zones, manifested the least diverse BMI fauna. Sites on Del Puerto Creek, Lone Tree Creek, and the downstream Orestimba Creek site were characterized by higher metal concentrations and less diverse BMI communities than sites in Bear Creek, Mud Slough, and Salt Slough. High metal and nutrient levels were correlated with poor riparian zones. The potential connection between metals, riparian vegetation, and BMI community integrity requires further investigation.

Seasonal differences were detected in BMI community integrity between the June and September sampling events. BMI community integrity (as measured by metrics) declined from spring to fall. This could be related to natural temporal variation, to seasonal influences of anthropogenic factors, or both.

Analyses suggested that metals, riparian zone quality, TOC, nitrogen, and organic wastes are determinants of BMI community integrity in SJR ADWs. However, cause-and-effect were not established in this study and establishing cause-and-effect is essentially impossible using solely a bioassessment procedure. Furthermore, caution should be exercised when interpreting the results of this investigation for a number of reasons, including the small size of the dataset (limited number of sites, one site on a waterway) and limited water quality data. It is not our intent to imply that metals, riparian zone quality, TOC, nitrogen, and organic wastes are the only or primary determinants of BMI community integrity in the lower SJR watershed. A combination of physical habitat (both instream and riparian), hydrology (flow regimes), and water quality factors interact to determine BMI community integrity in ADWs of the Central Valley.

An understanding of the strengths and limitations of methods is important in designing monitoring projects. Strengths and limitations of bioassessment procedures and recommendations for bioassessment use in the Central Valley were summarized in deVlaming et al. (2004). Bioassessment information can be an important component of comprehensive evaluations of aquatic ecosystem condition when used in concert with water and sediment chemistry and toxicity data (e.g., triad approach). This project was funded through the Surface Water Ambient Monitoring Program (SWAMP).

1. Introduction

In the Central Valley of California there are two major watersheds, the San Joaquin and Sacramento Rivers (Figure 1). These converge to form the Sacramento/San Joaquin Delta, which in turn discharges into San Francisco Bay. The San Joaquin River drains the middle portion of the Central Valley and flows north into the Sacramento-San Joaquin Delta. The San Joaquin River (SJR) drains a watershed of approximately 35,055 km^2. The major rivers in the SJR basin are the Cosumnes, Mokelumne, Calaveras, Stanislaus, Tuolumne, Merced, Chowchilla, and Fresno Rivers (Figure 2). The San Joaquin basin is characterized by an arid to semi-arid climate with hot dry summers and mild wet winters. The SJR basin receives an average precipitation of 38 and 13 cm in the northern and southern portions, respectively. The San Joaquin basin includes portions of three different U.S. Environmental Protection Agency ecoregions; the Sierra Nevada, the Southern and Central California Plains and Hills and the Central California Valley (Omernik, 1987). All the sites in this study are within the Central California Valley ecoregion. Agriculture is the predominant land use in the SJR basin (Gronberg *et al.*, 1998). Agricultural activities have resulted in extensive alterations of waterway geomorphology, hydrology, and water quality, as well as instream and riparian habitat degradation. Construction of dams, reservoirs, and vast irrigation and diversion systems have resulted in dramatic changes in the volume and timing of discharge to the San Joaquin River, as well as its discharge to the Sacramento-San Joaquin Delta (Gronberg *et al.*, 1998).

The agriculture-dominated segments of most waterways in the SJR watershed usually occur in the lower valley floor. These waterways are dominated either by water that will be used for irrigation or by irrigation runoff (Chilcott, 1992). Water quality issues facing this watershed include: Increased salinity in the lower river, resulting from reduced freshwater discharges to the San Joaquin and saline runoff from agricultural land; increased concentrations of trace elements that result from evaporative concentration of naturally occurring salts; pesticide contamination from agricultural runoff; and reduced dissolved oxygen (Gronberg *et al.*, 1998).

Water column chemistry and aquatic species toxicity studies in agriculture-dominated waterways (ADWs) of the Central Valley ecoregion documented impaired water quality conditions (e.g., Domagalski, 1996; de Vlaming *et al.*, 2000; Holmes and de Vlaming, 2003). Pesticides (including herbicides, insecticides, fungicides) totaling millions of kilograms are applied annually in the San Joaquin River basin (CDPR, 2003). Much of the toxicity to aquatic species in ADWs has been linked to insecticides (e.g., de Vlaming *et al.*, 2000). Bioassessment has been used to assess the health and integrity of aquatic communities in several areas of the United States and has proved to be an important tool for evaluating impacts from anthropogenic disturbances such as non-point source pollution and alterations of stream channels, riparian areas, and entire stream catchments (Fore *et al.*, 1996; US EPA, 2002). Benthic macroinvertebrate (BMI) communities are a critical component of stream ecosystems. Although there is considerable concern regarding health and integrity of biotic communities, few BMI community studies have been conducted on waterways in California's Central Valley.

The Central Valley Regional Water Quality Control Board funded an exploratory project with UCD ATL that was designed to assess benthic macroinvertebrate (BMI) community structure and habitat conditions in a variety of agriculture- (ADW) and effluent-dominated waterways in the lower San Joaquin River and the lower Sacramento River watersheds. The current study deals with the data from the San Joaquin River watershed. The Sacramento River bioassessment data has been published in a companion study (deVlaming *et al.*, 2004). An important aspect of the investigation was to identify environmental factors affecting BMI community health. Analyses in the Sacramento River study identified an association between agricultural and urban land uses and less healthy BMI communities (deVlaming *et al.*, 2004). Habitat (instream and riparian vegetation) conditions in ADWs were poor to marginal. Environmental variables associated with BMI community health included substrate, several physical habitat factors and some water quality variables. Downstream sites on ADWs tended to manifest more robust BMI communities than upstream sites surrounded by intense agricultural activities. That is, the most impacted sites were located adjacent to the highest intensities of agricultural activities. Of the environmental parameters measured, water quality parameters appeared to exert less effect on BMI community integrity than physical habitat factors.   DeVlaming *et al.* (2004) hypothesized that the effects of water quality parameters were difficult to detect with the bioassessment procedure because of reduced diversity of BMI fauna at most ADW sites, possibly associated with degraded physical habitat. DeVlaming *et al.* suggested that these waterways could support more robust BMI communities if physical habitat and water quality were less degraded by agricultural activities.

Applying the U.S. EPA Environmental Monitoring and Assessment Program (EMAP) procedure (Lazorchak *et al.*, 1998), relationships between environmental gradients and macroinvertebrate assemblages in lotic habitats of the California Central Valley were examined by Griffith *et al.* (2003). These investigators concluded that instream habitat was the primary determinant of the BMI fauna. In contrast to what has been reported in other studies of agricultural systems in the Central Valley, nutrients (nitrogen and phosphorus) appeared less important than specific conductivity and cation concentrations in determining BMI community composition. In the Griffith *et al.* study metrics appeared insensitive to cation and specific conductivity gradients. The authors speculated that such results related to level of taxonomic identification. Metrics rely on family or order level measurements, whereas detection of specific conductivity and ionic effects may require genus-level identifications.

Leland and Fend (1998) conducted artificial-substrate macroinvertebrate bioassessments in the lower San Joaquin River and associated tributaries applying a multivariate analysis approach. Salinity (dissolved solids) was identified as the major gradient associated with BMI community structure. In upstream locations macroinvertebrate community structure was indicative of degraded physical conditions.

Brown and May (2000) performed biological assessments (1993-97) on the lower Sacramento and San Joaquin River drainages as a component of the U.S. Geological Surveys (USGS) National Water Quality Assessment Program. Agricultural land use and salinity were found to be the major determinants factors associated with variation in BMI communities collected from snags in waterways in the lower Sacramento and San Joaquin River watersheds. Taxa identified by TWINSPAN (two-way indicator species analysis) as most likely to inhabit drains were crangonyctid amphipods, ceratopogonid dipterans, leeches, snails, flatworms, coenagrionid odonates, and elmid coleopterans. Macroinvertebrates in the San Joaquin River samples consisted primarily of corophiid amphipods, whereas fauna of Central Valley portions of tributaries draining the Sierra Nevada consisted of Ephemeroptera, Trichoptera, Odonata and naucorid hemipterans.

The objective of the current study was to assess BMI community structure and physical stream habitat conditions in several valley floor agriculture-dominated waterways in the lower San Joaquin River watershed at sites where monthly water quality data were being collected as part of California's Surface Water Ambient Monitoring Program (SWAMP). SWAMP water quality data were available at all but two of the sites examined in the current study. A further aim was to identify environmental factors that potentially affect BMI assemblage structure and integrity. The heavily managed aquatic ecosystems of the Central Valley, and their resident BMI communities, are poorly understood. As stated, these types of waterways are characterized by highly modified, or unnatural, conditions. While a study is currently underway to identify and characterize 'reference' or 'least disturbed' sites in low gradient waterways of the Central Valley, reference or 'natural' waterways had not been designated when this study was conducted. Anthropogenic habitat and water quality disturbances are likely to impact aquatic biota communities in these systems. Limited resources precluded evaluation of all potential stressors on aquatic ecosystem biota.

2. Materials and Methods

2.1 Site Selection Rationale and Locations

This investigation included 11 sampling sites, all located on waterways in the lower SJR watershed. Sites were visited in June and again in September 2001. Based on evaluations conducted in association with the Inland Surface Water Plan (Chilcott, 1992) and initial Central Valley Regional Water Quality Control Board (CVRWQCB) total maximum daily load (TMDL) activities, six sub-basins were identified in the San Joaquin River Basin (Figure 3): Each sub-basin is bounded by either the Sierra Nevada or Coast Range and is comprised of similar land uses and drainage patterns. All natural and constructed waterways were designated in each sub-basin. Potential water quality concerns and major representative discharges to the lower SJR also were summarized (Chilcott, 1992).

At least one sampling site was selected in each of the six sub-basins. Sites selected for bioassessment sampling, with the exception of one on the Cosumnes River and one on Orestimba Creek (see below), were chosen from among 38 long-term sites being monitored by the CVRWQCB in association with the Surface Water Ambient Monitoring Program (SWAMP). Funding limitations constrained the number of sites that could be included in this exploratory project. We did not anticipate, therefore, that results obtained from these 11 sites would be indicative of all waterways in the lower SJR sub-basins. With the exception of the site on Orestimba Creek at Bell Road and the site on the Cosumnes River at Michigan Bar, sites were located near the lower portion of the waterways, near the confluence with the SJR or other primary tributaries to the SJR. Land use around most sites was dominated by agriculture, with over 50 percent of flow originating from agricultural runoff. Nonetheless, the waterways selected for location of sites are important components of the aquatic systems in the sub-basins. Establishing baseline biological conditions in these representative waterways is critical to future investigations into aquatic system integrity and health. Bioassessment monitoring in these waterways is intended to link into the multi-constituent monitoring conducted in association with SWAMP and TMDL monitoring programs.

Description and locations of sampling sites are summarized in Table 1 and depicted in Figure 3. Following is a brief summary of the 11 sampling sites.

Northeast sub-basin—One site was located in the northeast sub-basin: Cosumnes River @ Michigan Bar (SAC 003). Although the Cosumnes is one of the few rivers in California that does not have a major in-stream impoundment there are several small drinking water reservoirs on tributaries. Flow in the Cosumnes consists primarily of input from snowmelt and off-stream reservoirs. The Cosumnes River is impacted by several sources including agricultural and urban land use. During summer months the Cosumnes is normally dry from immediately downstream of the Highway 16 Bridge in Rancho Murieta to its confluence with the Mokelumne River near Mokelumne City.

Eastside sub-basin—Two sites are situated in this sub-basin: Harding Drain @ Carpenter Road (STC 501) and Lone Tree Creek @ Austin Road (SJC 503). Harding drain is a waterway that discharges directly to the SJR. It is a constructed, soft bottomed channel that conveys agricultural runoff, discharge from the city of Turlock WWTF, and storm runoff from Turlock. Lone Tree Creek is a modified natural channel originating south of Woodward Reservoir in Stanislaus County. This mostly hardpan clay, ephemeral stream conveys runoff during and following large storm events. During the irrigation season Lone Tree creek conveys agricultural supply and return flows to its confluence with Little Johns Creek.

Southeast sub-basin—Bear Creek @ Bert Crane Road (MER 007) was the lone site in this sub-basin. Bear Creek is a sandy bottomed, slightly modified, natural eastside creek that receives the majority of its flow from Burns and Bear Reservoirs via the Merced River. The channel carries both irrigation supply and return flows, as well as seasonal discharges from heavy storm events. Bear Creek flows to the East Side Bypass then into the SJR upstream of the town of Stevenson.

Grassland sub-basin—Two sites were designated in this sub-basin: Salt Slough @ Lander Avenue/Highway 165 (MER 531) and Mud Slough North upstream of San Luis Drain (MER 536). Salt Slough is a perennial stream dominated by agricultural return flows and state, private, and federal wetland discharges. Mud Slough North also is a perennial waterway dominated by agricultural drain water and seepage from surrounding wetlands. During the spring flows in Mud Slough North are dominated by discharges from wildlife refuges and duck clubs.

Northwest sub-basin—Land use in this sub-basin is predominantly agriculture. Creeks in this area are naturally ephemeral, but valley floor sections convey irrigation supply and discharge for most of the year. Sampling occurred at four locations in this sub-basin: Orestimba Creek @ River Road (STC 019), Orestimba Creek @ Bell Road (STC 517), Del Puerto Creek @ Vineyard Road (STC 516), and Ingram Creek @ River Road (STC 040). Most of Orestimba Creek is an ADW and is one of the largest west-side tributaries. This creek is considered representative of other westside ADWs in terms of land use, and a historic monitoring database exists. The most upstream reach of Orestimba Creek (at Bell Road, STC 517) is a natural ephemeral stream that flows from the coast range during winter runoff and storm periods. Downstream of Eastin Road the entire creek to the confluence with the SJR is dominated by agricultural irrigation runoff. Orestimba Creek at River Road is an incised hardpan channel with large cobble in some areas.

Del Puerto Creek is an ADW west-side tributary to the SJR. The creek is ephemeral down stream of the CA Aqueduct, but receives agricultural return flows from April-September. Del Puerto Creek has been modified and channelized in certain reaches.

An ephemeral west-side tributary upstream of Interstate 5, Ingram Creek, conveys water for only 2 to 3 months per year. Downstream of Interstate 5, natural surface water only flows in the soft mud, sand, and small gravel bottomed creek during large storm events. The portion of the creek downstream of the Delta Mendota Canal was formerly a dry wash but has been straightened and channelized to convey irrigation runoff.

Sacramento-San Joaquin Delta sub-basin—The Delta sub-area contains over 16,000 km of waterways and is defined as the area north of Vernalis on the SJR, south of the I Street Bridge on the Sacramento River, and the Antioch Bridge as the western boundary. Delta water is derived from both the Sacramento and San Joaquin Rivers. Only one waterway in this sub-basin was included in this study: Mountain House Creek @ Byron Road (SJC 509). Mountain House Creek has been highly altered. Currently it is a constructed ephemeral channel. The lower 5.6 km of the creek is dominated by agricultural return flows. The creek discharges directly to Old River in the Delta. A completely new city of 55,000 (near Tracy Ca.) is slated for development over the next three years and will completely surround Mountain House Creek. (Dibble, C.S. SWAMP workplan 00-01).

2.2 Habitat Assessments and Water Quality Measurements

For a more comprehensive understanding of spatial variations in BMI community structure/integrity and potential causes of biotic disturbances, habitat assessments were conducted simultaneously with BMI collections. Physical habitat assessments were conducted at each site. These included two components: (1) the CSBP Worksheet that focuses on water quality and habitat parameters at the individual riffle/transect level and (2) the US EPA nationally standardized Habitat Assessment Field Data Sheet (Barbour *et al.*, 1999) that targets habitat conditions along the entire reach. Each of these physical habitat assessments has a low and high gradient version. Riffle/transect data collected included depth, velocity, and substrate composition. These measurements were recorded as the mean of three transect measurements. Substrate composition was recorded as an observational estimate of percentages of mud (<0.2 cm), sand (<0.2 cm), gravel (0.2 to 5.0 cm), cobble (5.0 to 25.0 cm), boulder (>25.0 cm), and bedrock/hardpan (solid rock or clay forming a continuous surface). Substrate consolidation was determined to be 'loose', 'moderate', or 'tight'. Gradient (percent slope) was determined as the change in elevation between upstream and downstream ends of a sampling reach.

Reach habitat data included estimates of ten physical habitat parameters (epifaunal substrate, sediment deposition, channel sinuosity, riparian vegetative zone width, pool substrate, available cover, channel flow status, bank stability, pool variability, channel alteration, and vegetative protection). Each habitat parameter was scored from 0 – 20, divided into quartile categories of 'poor', 'marginal', 'sub-optimal', and 'optimal' scoring categories. Each habitat parameter is scored using semi-qualitative criteria (Barbour *et al.*, 1999). Water quality measurements were recorded prior to collection of BMIs at the second riffle/transect (CDFG, 2003). Measurements included pH, specific conductance (SpC), dissolved oxygen (DO), and temperature. Collection of water quality data occurred at the time of BMI sampling and on a fixed monthly monitoring program.

Monthly monitoring consisted of SpC, DO, pH, temperature, hardness, alkalinity, and turbidity determinations as well as measurements of metals, nutrients, total organic carbon (TOC), and biochemical oxygen demand (BOD) throughout the study. Canopy cover was estimated with a hand held densiometer. At high gradient (slope > 0.2) sites, gradient was measured using a stadia rod and a clinometer. GPS coordinates were recorded at the second riffle/transect of all sites.

Metal concentrations in site water samples were determined according to US EPA method 200.7 at Twining Laboratory in Fresno, CA. Nutrients in these site water samples were analyzed at Twining Laboratory or under the direction of Dr. Randy Dahlgren at the University of California, Davis, Department of Land Air and Water Resources. Procedures followed were US EPA method 300 for nitrate and ortho-phosphate, 350.3 for ammonia, 4500 for total nitrogen (Kjeldahl), and 365.3 for total phosphorus.

2.3 Macroinvertebrate Sampling

Benthic macroinvertebrate (BMI) sampling was conducted using a modified low gradient sampling method of the California stream bioassessment procedure (CSBP—CDFG, 2003). Due to the absence of riffles at the sampling sites, this method involves sampling three randomly selected transects within a 100-meter channel reach. Sampling low gradient, fine substrate-dominated streams using a modified low gradient CSBP sampling adaptation required identification of 100 meter standardized reach lengths at each site. Transects were chosen at random from all possible meter marks. Three locations across each transect were sampled, making sure to target the best, or richest, habitats available in each transect. Transects consisting of homogenous substrate/habitat, were sampled at the bank margins and thalweg. A 500 um mesh D-frame kick net was placed immediately downstream of a transect and a 0.3 X 0.6 meter of substrate upstream of the net was disturbed. Disturbing the stream bottom included kicking and turning over and scrubbing of all large debris (cobble, wood chunks, gravel, leaves). The three 0.3 X 0.6 meter transect samples were composited into a sample container and preserved in 95 percent ethanol. This process was repeated at the remaining two randomly chosen transects.

2.4 Sub-sampling and Taxonomy

In the laboratory, three hundred organisms were sub-sampled and removed from each transect composited sample for taxonomic identification, metric analyses, and abundance estimations. Sub-sampling consisted of: (1) transferring each sample to a 500 um sieve, gently rinsing to flush out fine particles, (2) removing large debris such as gravel, fresh leaves, and sticks after thoroughly inspecting for entangled BMIs, (3) submerging the sieve containing BMI's in a 2.5 liter container of water to homogenize the sample, (4) draining the sieve, and (5) inverting the sieve over a white tray with numbered grid lines. Samples were spread evenly over 5X5 cm grids so as to accommodate the entire sample volume. Grids to be examined by dissecting microscope were selected at random. BMIs were removed from grids and transferred to a vial containing 70% ethanol (EtOH) until a 300 count was achieved. The last grid examined to achieve the three hundred count was completely processed, with additional BMIs placed into an 'extras' vial. BMIs from the 'extra' vial are necessary for an accurate estimate of sample BMI abundance. Sample abundance was estimated as the total number of BMIs removed from a sample, divided by number of grids processed, multiplied by total number of grids covered by the sample.

2.5 Laboratory and Field Performance Evaluation

To assure that data generated were of high quality and credible, performance evaluation (quality assurance) measures were included in this study. Both internal (University of California, Davis Aquatic Toxicology Laboratory; UCD ATL) and external performance evaluations on taxonomic identification were a component of this study. Internal evaluation consisted of re-identification by a second taxonomist of BMIs randomly selected from 10 percent of all samples. External performance evaluation was performed by the CDFG Bioassessment Laboratory, Rancho Cordova, CA on 20 percent of all samples. A total of 11 samples were evaluated. There were no major discrepancies between UCD ATL identifications and those of CDFG (misidentifications in only 4 percent of 138 taxa vials). These performance evaluations lend credibility to the taxonomic identification presented herein.

Prior to actual sampling, field crews engaged in trial runs to assure consistency of sampling efforts and habitat scoring. Habitat scoring was monitored by the project manager.

For quality assurance of sub-sampling, a UCD ATL internal performance evaluation was conducted. Ten percent of all samples were subjected to re-evaluation. Our sub-sampling criterion for this investigation was that no more than ten percent of the BMIs in a sample could be overlooked. No remnant samples exceeded the ten percent criterion; in a majority of samples less than five percent of BMIs were overlooked.

2.6 Data Analysis

Multivariate and multimetric analyses were applied to investigate spatial and temporal variability in BMI communities. Relationships between community structure, a range of environmental variables describing habitat and water quality, and a number of widely used metrics indicative of BMI community integrity were also examined. Where data conformed to assumptions of normality and homogeneity of variance, parametric statistics were performed, otherwise nonparametric equivalents were used. The significance of multiple simultaneous tests was evaluated after sequential Bonferroni correction, which adjusts the tests to be less likely to indicate a significant difference where one does not exist.

2.6.1 Community Composition

Community composition was probed using hierarchical cluster analysis, indicator species analysis, and ordination by nonmetric multidimensional scaling (NMS) to reveal the strongest patterns in BMI community structure across sites. Hierarchical cluster analysis lumped sites into groups based on similarity in BMI communities. Indicator species analysis (Dufrêne and Legendre, 1997) revealed the taxonomic differences between the clusters of sites, and between seasons. NMS ordination created axes that summarize BMI assemblages based on the proportions of taxa at the sites.

Proportional abundance of taxa (# of individuals of a given taxon / total # individuals collected) was used in all statistical analyses, as opposed to estimated absolute abundance, because the CSBP sampling and sample processing method is not designed to determine actual abundances at a site. The proportional abundance data were arcsine-square root transformed to moderate the influence of common and rare taxa. Taxa occurring only at one site (rare taxa) were excluded from statistical analyses to improve resolution of commonalities among sites.

Cluster analysis and ordination rely on calculation of a distance measure to quantify taxa composition similarities among sites. Sorenson distance, which has been shown to be a more accurate representation of community structure than Euclidean distance, was used as a measure of overall site similarity (McCune and Grace, 2002). Cluster analyses and ordinations were performed using PC-ORD 4.0 (McCune and Mefford, 1999).

2.6.2 Cluster and Indicator Species Analysis

Hierarchical cluster analysis connected the sites through a tree-like dendogram, with more closely connected branches indicating sites with similar community compositions. Cluster analyses were performed using flexible beta linkage (β = -0.25) because this method is compatible with the Sorenson distance measure. Also, with β = -0.25, results are consistent with Ward's method, which accurately represents similarities in community structure and cluster discreteness (McCune and Grace, 2002).

Indicator species analysis (Dufrêne and Legendre, 1997) was applied to identify taxa associated with site clusters and to evaluate efficacy of the cluster analysis for differentiating sites representing discrete communities. Indicator species analysis was also performed using the sampling events (June and September) as categories, in order to identify seasonal variability in community composition. Indicator values were computed for all taxa based on their relative abundance and frequency of occurrence in each cluster.

2.6.3 Nonmetric Multidimensional Scaling (NMS) Ordination

Ordination by nonmetric multidimensional scaling (NMS) was used to reveal common patterns in community structure across sites. Further, NMS ordination created axes that summarized variability in community composition. Correlations with these axes showed the strength and direction of associations between species composition, environmental variables, and metrics indicative of BMI community integrity.

Seasonal variation may influence diversity and abundance of BMI communities. We sought to capture this seasonal variation by performing a single ordination on the entire dataset, including samples taken during both the June and September sampling events.

NMS ordination was used to observe the relative positions of the sites along gradients representing aspects of the benthic macroinvertebrate community structure. Sites with similar communities appear close to one another in the ordinations. NMS is well suited to summarizing nonlinear associations among the abundances of a large number of rare species (McCune and Grace, 2002). NMS is distance-preserving: it maintains the rank-order of dissimilarity values between the sites. It is an iterative optimization method that improves the fit of the ordination to the original distance matrix through a series of small steps, until a stable, well-fitting solution is obtained.

NMS was performed with random starting coordinates and a step length of 0.20. Forty starting configurations were used, and for each starting configuration solutions were computed using dimensionalities ranging from 2-6 dimensions. The lowest stress solution for each dimensionality (in which the distances in the ordination space most resemble the distances in the original distance matrix) was compared to the lowest stress solutions for the other dimensionalities. The solution chosen was the highest dimensionality solution with a final stress more than 5 units lower than the next lower dimension, provided that the solution had a stress lower than 95% of 50 solutions calculated at that dimensionality with randomized data (McCune and Grace, 2002).

NMS was selected in preference to canonical correspondence analysis (CCA) because in CCA the pattern of biological samples is constrained by the environmental variables included in the analysis. With NMS, measured environmental variables do not bias the ordination of biological data. This yields a more accurate picture of the overall community structure.

2.6.4 Taxonomic Composition, Environmental Variables, and BMI Metrics Gradients

Pearson product-moment correlations between the NMS axes and taxa proportional abundance revealed the major taxonomic gradients represented by the axes. Correlations between these axes and environmental variables and BMI metrics indicative of community integrity indicated the strength and direction of environmental gradients (i.e., environmental parameters likely to be determinants of community structure) and gradients of BMI community integrity (i.e., indication of community structure changes relevant to community integrity/health) associated with each axis, respectively. Environmental variables examined include water quality parameters as well as measures of substrate and physical habitat.

To further investigate potential associations between environmental variables and community integrity, we examined Pearson product-moment correlations between environmental variables and BMI metrics. This analysis focused on metals, nitrogen, biochemical oxygen demand (BOD), and total organic carbon (TOC), which NMS ordination indicated as likely candidates for affecting BMI community integrity. For this analysis the concentrations of all metals correlated with the NMS axes (Cr, Ni, Zn, Cu, Pb) were summed as an overall measure of metals contamination.

3. Results

3.1 Habitat Conditions

Total habitat quality scores ranged between 46 (poor) and 133 (sub-optimal) for habitat assessment in June 2001 (Figure 4). Bear Creek, Mud Slough North, and Salt Slough manifested the highest habitat quality scores (114 – 133) in June. These sites were not assessed in September. Sites on Del Puerto Creek, Lone Tree Creek, and downstream Orestimba Creek were characterized by marginal habitat quality in June. The upstream site on Orestimba Creek was categorized as sub-optimal. Ingram Creek, Mountain House Creek, and the Harding Drain had the lowest overall habitat quality scores in June.

In general, the sites with the highest habitat quality scores were characterized by lesser degrees of physical channel alteration, greater bank stability, greater amount of bank vegetative protection, and larger riparian zones (12 to 18 meters, or greater). However, Bear Creek was an exception, with generally good physical habitat, but a riparian zone similar to sites with the most impaired habitat (riparian zones nonexistent to less than 6 meters). Sites with the lowest overall habitat quality scores were characterized by streambeds dominated by heavy deposits of fine material, high level of physical channel alteration, lack of channel sinuosity, more unstable banks, little to no vegetative bank protection, and no riparian zones.

Substrate composition was dominated by fines (mud), with lesser percentages of sand and gravel at most sites (Figure 5). Bear Creek, Mountain House Creek, Mud Slough North, Salt Slough, Ingram Creek, and Harding Drain were dominated by the greatest percentages of fine sediments. In contrast, Lone Tree Creek was dominated by sand and hardpan substrates, with lesser amounts of mud. Substrate composition at the Del Puerto Creek site and both the upstream and downstream Orestimba Creek sites were comprised of about 50 percent of gravel, although this gravel was small and very embedded in fine substrates. Substrate composition at the Cosumnes River site was typical of a low gradient alluvial river, comprised of a mix of fines, gravel, cobble, and boulders. Natural cobble was found in upstream Orestimba creek (at Bell Road) and in the Cosumnes River. Cobble-sized substrate found at other sites was actually concrete riprap.

Habitat quality scores observed in September 2001 were similar to those measured in June. Ingram Creek had the lowest of the habitat quality scores in the September sampling event and June sampling events. Ingram Creek was characterized by a high level of sediment deposition, high level of physical channel alteration, unstable and eroded stream banks, no vegetative bank protection, and nonexistent riparian zones.

3.2 Community Composition

Cluster analyses were applied to divide sites into groups with communities composed of similar taxa. These analyses served to render very complex data into a more comprehensible form and to facilitate the statistical exploration of community integrity and identification of environmental variables that potentially determine community structure and integrity. Cluster analyses revealed that the upstream reach site on Orestimba Creek and the Cosumnes River site were taxonomically distinct from sites surrounded by intensive agricultural activity (Figure 6). Table 2 indicates the most common taxa present at the three major types of sites examined (agriculture-dominated sites, upstream Orestimba Creek, and the Cosumnes River). Oligochaetes, chironomid midges, and flatworms dominated the agriculture-dominated sites. The upstream Orestimba site contained a more diverse fauna including *Caenis* mayflies, chironomids, damselflies, and amphipods. The Cosumnes River site was also characterized by a diverse fauna, which included chironomids, elmid beetles, and black flies. The June samples show the southern sites (Mud Slough North, Salt Slough, and Bear Creek) as having similar communities, but examination of the September samples did not show that the community in Salt Slough was distinct from the communities at the more northern sites. BMI metrics and indicator species analysis of data collected in June showed that communities at sites surrounded by intense agriculture showed a wide range in terms of diversity and pollution tolerance. Indicator species analysis of data collected in September suggested BMI community structure differences at sites surrounded by intense agriculture, but BMI metrics did not support differences among those sites.

A three-dimensional solution to the NMS analysis fit the dataset effectively while using few dimensions to summarize the variation in the dataset (Figure 7). This NMS ordination facilitates visualization of taxa composition similarities among sites—proximity of points represents similarity of taxa composition at sites while remoteness of points connotes dissimilarity of taxa composition at sites. The NMS ordination depicts the three major components of variability in BMI community composition between the sites examined. Each axis represents a gradient among sites where oligochaetes dominate (negative values) and sites where a high diversity of other taxa are present (positive values). Both June and September samples collected at the upstream Orestimba Creek site (STC 517) were divergent from the remainder of sites in terms of taxa composition.

3.3 Environmental Parameters Related to Differences in BMI Community Structure

The cluster analysis indicated groups of taxonomically similar sites, and associations of environmental parameters with these clusters can reveal environmental factors potentially important to the composition of the BMI community. Comparisons of mean values of environmental parameters among clusters revealed that metal concentrations (copper, lead, and zinc), riparian zone quality, TOC, total nitrogen concentration, and organic matter levels differentiated the clusters of agricultural-influenced sites (Table 3, Table 5, Figure 8). Sites characterized by lower metal, TOC, nitrogen, and organic matter concentrations and possessing more intact riparian zones contained more diverse BMI communities, including *Caenis* (mayflies) and *Gammarus* (amphipods). Cluster analysis of the June dataset showed that sites in the Ag3 cluster (with the highest metal concentrations and the poorest riparian zones) contained the least diverse BMI fauna (Tables 3 and 4). Sites in the June Ag2 cluster were characterized by higher metal concentrations and less diverse BMI communities than sites in the Ag1 cluster, despite the fact that sites in the Ag2 cluster consisted of high proportions of (highly embedded) gravel substrates. Lack of metal and nitrogen data at the less agriculture-influenced sites (STC 517 and SAC 003) precludes inferences concerning the roles of these factors in determining differences in BMI communities among sites surrounded by various intensities of agricultural activities. Among samples collected in September, sites in the

Ag1 cluster were distinguished by the highest metal concentrations and poor riparian vegetation (Table 5). This cluster also was characterized by more pollution-tolerant indicator taxa (Figure 8), but metrics did not indicate a difference in diversity between the Ag1 and Ag2 clusters (Table 6).

Correlations among BMI community composition, BMI metrics, and environmental variables elucidated a clear pattern in the ordination axes (Figure 9, Tables 7-9). Each NMS axis was associated with a discrete set of environmental parameters, as well as a discrete set of taxa that appear to respond to changes in these environmental parameters (Figure 9). On all three axes, positive values appear to indicate healthier BMI communities, showing clear gradients of oligochaete to insect dominance. Proportional abundances of many insect taxa were positively correlated with NMS axes, while abundances of the oligochaete (worm) taxa, Tubificidae and Naididae, were negatively correlated with these axes (Table 7). Positively correlated with NMS axis 1 were *Bezzia* (Ceratopogonidae) as well as *Hyalella* and many insects, while negatively correlated with this axis were the Naidid oligochaetes. Ceratopogonidae (biting midges) are known to be extremely tolerant to organic pollution and anoxic conditions. Their grouping with the other insect taxa as positively correlated with NMS axis 1 indicates that the most important variability in community composition in this dataset was not between pollution-sensitive and pollution-tolerant insect communities, but rather between communities containing insects and those largely bereft of insect taxa. The other two axes expressed similar gradients: Naididae to *Fallceon* (Ephemeroptera) on axis 2 and Tubificidae to diverse arthropod taxa on axis 3.

Axis 1 gave evidence of relationships between metals (copper, lead, zinc) concentrations and the BMI community structure and integrity (Figure 9). Sites with high metal concentrations were dominated by Naidid oligochaetes, while sites with lower metals concentrations, wide riparian zones, and wide channels were inhabited by a diverse array of BMIs, and manifested greater numbers of Ephemeroptera taxa, EPT taxa, and higher abundances of BMIs overall (Tables 7-9). Axis 2 indicated relationships between Total Organic Carbon (TOC) and BMI community structure. High TOC was associated with dominance of Naidid oligochaetes, while low TOC was associated with the presence of *Fallceon* (Ephemeroptera) and flatworms. Axis 3 was linked with eutrophication. Sites with high nitrogen and biochemical oxygen demand (BOD—indicative of organic matter) were characterized by dominant populations of Tubificid oligochaetes, while less eutrophic sites consisted greater numbers of Trichopterans, Orthocladiinae (chironomid midges), and the mite, *Sperchon*. Physical habitat, including wider riparian zones and more natural (less altered) channel morphology, was of higher quality at the less eutrophic sites.

The association of BMI metrics and environmental variables with NMS axes suggests that the ordination successfully depicts BMI community structure indicative of community health. Ordinations and cluster analyses were consistent in identifying metals, TOC, nitrogen, and organic matter (indicated by BOD) as important stressor gradients (likely determinants of BMI community integrity).

Pearson product-moment correlations highlighted the strongest associations between BMI metrics and environmental variables correlated with NMS axes (metals, nitrogen, BOD, TOC—Table 10). Moderately strong negative correlations of metal concentrations with insect taxa and oligochaetes were detected. Metal concentrations were positively correlated with Planariidae (flatworms) abundance. BOD5 and BOD10 showed negative correlations with taxonomic richness and insect abundance, and showed positive correlations with BMI pollution tolerance, proportional abundance of the most dominant taxon, and oligochaete (segmented worms) abundance. Nitrogen (Kjeldahl) correlations were similar to those of BOD, but of lesser strength. Diversities of insect and non-insect taxa were both negatively correlated with TOC. Positive correlations of TOC with percent EPT and ETO abundance appeared related to high TOC and high Caenis (Ephemeroptera) abundance at the upstream Orestimba Creek site (STC 517).

3.4 Seasonal Changes in Community Composition

Every site sampled in both June and September scored lower on NMS axis 1 using September sampling event data, indicating a clear seasonal change in BMI community structure (Figure 10). The seasonal change in NMS axis 1 scores was significant (paired t-test, t = -6.39, df = 6, *P* = 0.0007). Although NMS axis 1 correlated with metals concentrations (Table 9), no metals were found in significantly greater concentrations in September compared to June (paired t-tests, df = 5, NS). However, a trend towards higher metals concentrations in September was apparent, and low sample size limited the statistical power of this test.

Indicator species analysis by season revealed that *Simulium* and *Physa*/*Physella* were characteristic of June samples, whereas Naidid oligochaetes were characteristic of September samples.

4. Discussion

4.1 Community Composition and Integrity

Analysis of data collected in the lower SJR watershed revealed considerable differences in composition and health of the BMI communities among sites. Even among sites surrounded by intense agriculture some sites were characterized by more extreme BMI community degradation than others. Sites ranged from those consisting mostly of oligochaetes to those characterized by large populations of amphipods and dipterans, as well as some Ephemeroptera (mayflies), Trichoptera (caddisflies), and Odonata (damselflies and dragonflies). Although sample sizes were too low for statistical analysis, cluster analyses indicated that clusters of sites surrounded by intense agriculture differed from one another in BMI metrics (community health) during both June and September. These results indicate that major differences in community composition among agricultural-influenced sites were related to differences in community integrity. Percent tolerant organisms and percent insects, in particular, differed among clusters. Indicator species analysis revealed that *Caenis* (mayflies), *Berosus* (beetles), chironomid midges, Astacidae (crayfish), and *Gammarus* (amphipods) characterized the site clusters manifesting the highest BMI community integrity. Site STC 517, upstream of most agricultural influence, manifested a large *Caenis* population. Surprisingly, similarity in BMI communities did not appear to relate strongly to geographical proximity of sites, although the June samples taken at the southernmost sites were distinct from the other samples taken in June. BMI communities at sites in the eastern sub-basins of the SJR watershed were not particularly different than those in western sub-basins.

4.2 Factors Potentially Affecting BMI Community Integrity

Stressor gradients correlated with community degradation were metals, TOC, organic matter, and elevated nitrogen (Kjeldahl). We are not aware of other studies examining the low gradient waterways of the Central Valley that link metals and nitrogen to BMI community health. Both cluster analyses and NMS ordination indicated the importance of metals and nitrogen to BMI community composition and health. Metals correlated with the NMS axis that accounted for greatest portion of BMI community composition and clear differences in metals concentrations were seen among site clusters differing in community composition. TOC is also a likely water quality stressor on BMI communities since this parameter was strongly correlated with NMS axis 2. Nitrogen (Kjeldahl) levels and BOD (indicative of organic matter) were highly correlated with NMS axis 3 and were high in site clusters with lower BMI community health. Our analyses suggest that within the limited scope of this dataset, metals, TOC, organic matter, and nitrogen may rival habitat factors as determinants of BMI community integrity. This conclusion is supported by a comparison of conditions in the June Ag1 and June Ag2 site clusters. The less diverse June Ag2 clusters contained substrates more conducive to benthic insect colonization (more gravel), but was characterized by higher metal concentrations. High metal and nitrogen levels were correlated with poor riparian zones. The potential connection between metals, riparian vegetation, and BMI community integrity requires further investigation. However, these results support the hypothesis (Muscutt *et al.*, 1993; Lin *et al.*, 2002) that an intact riparian zone acts as a contaminant filter, preventing or reducing waterway pollution.

High metal concentrations have been linked to impacted BMI community integrity (e.g., Roback and Richardson, 1969; Armitage, 1980; Winner *et al.*, 1980; Fucik *et al.*, 1991; Clements *et al.*, 1992; Reice and Wohlenberg, 1993; Clements, 1994; Clements and Kiffney, 1994; Kemble *et al.*, 1994; Kiffney and Clements, 1994; Vinyard, 1996;

Clements *et al.*, 2000; Soucek *et al.*, 2000; Luoma *et al.*, 2001; Mebane, 2001). EPT metrics as well as relative abundance of Ephemeroptera (particularly Heptageniidae) and Odonata appear particularly sensitive to metal contamination. Many studies and review articles document that metal impacts on BMI communities are cumulative/additive. Therefore, a cumulative water quality objective for metals may be needed in addition to individual metal objectives.

Of note is that water column toxicity testing with C*eriodaphnia dubia* appears to be an effective predictor of metal impacts on BMI community integrity (Fucik *et al.*, 1991; Soucek *et al.*, 2000). It is not our intent to imply that metals, TOC, organic matter, and nitrogen are the only or primary potential determinants of BMI community integrity in the lower SJR watershed. As suggested in a companion study (deVlaming *et al.*, 2004), a combination of physical habitat (both instream and riparian), hydrology (flow regimes), and water quality factors interact to determine BMI community integrity in ADWs of the Central Valley.

Sediment samples collected at two sites (STC 516 and STC 019) utilized in this study produced significant *Hyalella azteca* (endemic amphipod) mortality. Pyrethroid insecticides were the likely cause of amphipod mortality in sediment samples collected at the Del Puerto Creek sites in March and August 2003 (Weston *et al.*, 2004 and personal communication). These data suggest that pyrethroid and other insecticides are likely to be impacting BMI communities in ADWs. Further, sediment toxicity testing and chemistry are very informative companion procedures when investigating impacts on BMI community integrity.

4.2.1 Water Quality Parameters

Water quality factors other than metals, TOC, nitrogen (Kjeldahl), and organic matter are likely to be determinants of BMI community structure in the lower SJR watershed, but were not detected because the number of water quality parameters measured in this study was limited. Few bioassessment studies, including the current one, have thorough and complete water quality data because funding is usually too limited to provide this data over a large area and over the duration of an entire study. While physical habitat factors remain relatively constant temporally, many water quality variables vary considerably through time. Habitat features and water quality parameters often co-vary, confounding attempts to discriminate the factors most responsible for BMI community perturbations. Each water quality variable is measured independently, but BMI communities almost certainly respond to additive, synergistic, and/or cumulative effects. Statistical analyses cannot detect all water quality variable interactions. DeVlaming *et al.* (2004) identified primarily habitat factors that influenced BMI communities and suggested that degraded habitat might constrain the ability of bioassessments to discern water quality impacts on BMI communities. Habitat quality at most sites in this study was sub-optimal, indicating more intact habitat than the poor to marginal habitat present at the agricultural sites examined by deVlaming *et al.* (2004). This higher habitat quality, along with the wider variety of water quality variables measured, including metals and TOC, could explain the greater success of this study in identifying water quality stressor gradients. Our analyses indicated a relationship between metals, TOC, organic matter, and nitrogen (Kjeldahl) with BMI community structure.

Habitat scores at both Orestimba Creek sites were in the sub-optimal range, but the downstream (agriculture-influenced) site manifested a slightly higher score. Biological condition, however, was considerably higher at the upstream site which was not in close proximity to agricultural activity. We hypothesize that the more impacted state of the downstream BMI community was related to water quality differences between the sites, with the upstream site experiencing less agricultural chemicals, organic matter, and sediment.

4.2.1.1 Specific Conductivity

Specific conductivity did not correlate with differences in BMI community composition or metrics. These results are inconsistent with previous studies on macroinvertebrates in the lower San Joaquin River watershed (Gronberg *et al.*, 1998; Leland and Fend, 1998; Brown and May, 2000; Griffith *et al.*, 2003). Our dataset was limited so results related to specific conductivity are inconclusive.

Leland and Fend (1998) investigated the association of some water quality factors with macroinvertebrate fauna in the lower San Joaquin River. They used artificial substrate and BMI approaches, applying canonical correspondence (CCA), metrics, and indicator species analyses. A basin-wide pattern in community response (metrics) to salinity (total dissolved solids-TDS, equivalent to specific conductivity) was detected with the standardized stable artificial substrate. TDS accounted for a large part of variance in artificial substrate assemblages over all seasons, flow conditions, and irrigation regimes. Biota communities on stable (artificial) and unstable substrate were highly dissimilar. Compared to the artificial substrate findings, there was a weaker statistical relationship between BMI community metrics and water quality variables. That is, artificial substrate data were superior to BMI surveys in distinguishing water quality variables that influence BMI community structure.

According to Brown and May (2000), specific conductance and temperature were the water quality variables most important to differences in BMI communities collected from snags in low gradient waterways in the lower San Joaquin River watershed. In contrast to the current study, the snag substrate is a fairly constant substrate, facilitating identification of water quality factors that have the potential to affect macroinvertebrate populations and communities. Griffith *et al.* (2003) suggested that specific conductivity was an important determinant of BMI community composition, but not necessarily associated with BMI metrics, in the Sacramento and San Joaquin River watersheds. The deVlaming *et al.* (2004) study on the lower Sacramento River watershed implicated specific conductivity, hardness, alkalinity, and phosphorus as water quality components likely to affect BMI community structure.

4.2.1.2 Pesticides

In ADWs, pesticides, particularly insecticides, are potential BMI community stressors. While pesticides may have contributed to the impacted BMI community integrity in ADWs, the current study was not designed to distinguish pesticide impacts on BMI. However, there is considerable evidence that insecticides have significant impacts on

BMI communities (Cuffney et al, 1984; Scherer and McNicol, 1986; Sibley *et al.*, 1991; Liess *et al.*, 1993; Lugthart and Wallace, 1992; Liess and Schulz, 1996; Schulz and Liess, 1997; Liess and Schulz, 1999; Schulz and Liess, 1999; Anderson *et al.*, 2003a, b; Hunt *et al.*, 2003; Phillips *et al.*, 2004). deVlaming *et al.* (2004) summarized several of these studies.

4.2.2 Agricultural Land Use

BMI communities at the upstream Orestimba Creek and Cosumnes River sites were more intact than at all other agriculture-dominated sites in the lower SJR watershed. We propose that these results relate to the many agricultural activities (e.g., modification of waterways and riparian vegetation, alteration of hydrology, impacts on water quality due to use of agricultural chemicals and fertilizers) that impact aquatic systems. Brown and May (2000) discovered that agricultural and urban land uses were strongly associated (negative correlation) with macroinvertebrate community structure and metrics in the lower San Joaquin River watershed. In the companion study to this project deVlaming *et al.* (2004) observed that sites in the lower Sacramento River watershed surrounded by intensive agricultural activities were characterized by degraded BMI community health. While the application of bioassessments to assess the effects of agricultural land use on aquatic ecosystem biological communities has been limited, other studies document that many farming activities degrade stream/river water quality and habitat, as well as significantly impacting BMI communities (Kendrick, 1976; Dance and Hynes, 1980; Schofield *et al.*, 1990; Delong and Brusven, 1998; Kay *et al.*, 2001). DeVlaming *et al.* (2004) summarized several studies that link agricultural activities to degraded biological conditions in aquatic systems.

4.2.3 Physical Habitat Factors

Physical habitat, including riparian vegetation and flow regimes, is a major determinant of aquatic biological community composition (e.g., Karr, 1991; Barbour *et al.*, 1996, 1999). While chemical pollution continues to be an issue in many freshwater ecosystems, habitat degradation is considered responsible for more biological impairment than caused by chemicals (Rankin, 1995). According to Cooper (1993), protection and remediation of habitat are the most effective means of conserving and restoring aquatic ecosystem biological diversity. In the current investigation, however, analyses indicated few (e.g., waterway width and riparian vegetation) physical habitat factors as potential determinants of BMI community structure and integrity. The reasons that our analyses did not identify more physical habitat factors as potential determinants of BMI community integrity are not clear. One possibility, however, is that substrate was similar (primarily mud and sand) at most ADW sites in this study. Excluding the lower site on Orestimba Creek (STC 019—where evidence points to water quality impacts), the agriculture-dominated sites with the highest habitat scores were MER 536 and MER 531. BMI metrics at these sites indicated a more intact community integrity compared to other agriculture-dominated sites. Sites with the lowest habitat scores were STC 040, SJC 509, and STC 501. BMI community integrity at these sites was among the lowest of agriculture-dominated sites. Therefore, there are definite indications in this SJR dataset that habitat factors are determinants of community integrity.

Other investigations of low gradient ADWs in the Central Valley have isolated physical habitat factors as probable determinants of BMI community integrity. Even among highly degraded low gradient ADWs in the lower Sacramento River watershed, a range of habitat quality was evident (deVlaming *et al.*, 2004). In that study, coarse substrates and higher physical habitat scores were associated with healthier BMI communities at low gradient ADW sites. Sites with plentiful submerged or emergent macrophytes or relatively ample gravel substrates contained more diverse BMI fauna than mud-dominated sites with few plants.

Griffith *et al.* (2003) examined relationships between environmental gradients and macroinvertebrate assemblages in the Central Valley portions of the Sacramento and San Joaquin River watersheds. According to these authors the probable primary environmental determinants of BMI assemblages in the Central Valley are instream habitat, including substrate type: (1) By metrics analysis—channel morphology and substrate, and (2) By taxa abundance analyses—specific conductivity, channel morphology, and substrate. Channel management activities and landscape scale alterations of catchments by agriculture were identified by these authors as the major activities responsible for the environmental factors determining BMI assemblages. In this study, comparable to our results, more homogenous instream habitat and substrate was associated with lower taxa richness and higher mean tolerance value. Brown and May (2000) investigated associations between macroinvertebrate assemblages and environmental variables in the lower San Joaquin and Sacramento River drainages. Their analyses indicated that dominant substrate type was highly associated with BMI metrics.

The primary goal of a study conducted by Hall and Killen (2001) was to characterize physical habitat and BMI communities in Orestimba Creek (an agriculture-dominated stream that discharges into the San Joaquin River) and Arcade Creek (an urban creek in Sacramento that discharges into Steelhead Creek) a tributary to the Sacramento River. A second objective of this study was to assess potential impacts of organophosphorus (OP) insecticides, particularly chlorpyrifos, on BMI communities in these two streams. The CSBP procedure was applied to ten sites on each creek. The Hall and Killen report provides a qualitative characterization of some physical habitat factors in Orestimba and Arcade Creeks in late spring. BMI communities in both creeks were relatively impoverished and dominated by oligochaetes and chironomids. Hall and Killen concluded that habitat factors likely explained the differences in BMI communities in Orestimba Creek and suggested that contaminants played a minor role. In an ATL review of the data provided in the Hall and Killen report, we found that the most downstream Orestimba sites in the Hall and Killen dataset were impacted by water quality factors. The data considered in the present study also indicated that BMI community integrity at the downstream Orestimba site was likely affected by water quality factors.

4.2.4 No Cause-and-Effect Established

Data presented herein suggested that metals, instream habitat, waterway width, TOC, nitrogen, and organic matter contribute to determining BMI community structure and integrity. These relationships were, however, determined by correlation so cause-and-effect was not established. The variables that correlated with BMI community structure and integrity could have been co-variables of factors that were not measured, but were the actual determinants. Several researchers (e.g., Barbour *et al.*, 1996; Clements and Kiffney, 1996; Holdway, 1996; McCarty and Munkittrick, 1996; Wolfe, 1996; Power, 1997; Bart and Hartman, 2000; Adams, 2003) have addressed the inability of bioassessment to establish a direct cause-and-effect relationship between stressors and biological communities. According to the National Research Council (2001), bioassessments do not provide precise enough determination of causes and sources of impairments to satisfy water quality management needs. Further, the National Research Council (2001) concluded that bioassessments should be used in conjunction with physical, chemical, and toxicological data in assessing aquatic ecosystem conditions.

4.3 Metrics Useful in Agriculture-dominated Waterways of the Lower San Joaquin River Watershed

This study revealed a set of metrics that we believe will be useful in evaluating BMI community integrity in the lower San Joaquin River watershed. The metrics with the greatest ranges at sites surrounded by intense agriculture that are likely to be useful indicators of relative BMI community integrity include Percent Tolerant Organisms, Percent Dominant Taxon, Percent Chironomidae, Percent Oligochaeta, Percent Insects, Percent Collectors, and Percent Predators. Low richness of EPT and Odonata (dragonfly/damselfly) taxa indicated potential metal impacts on BMI community integrity. High concentrations of metals also were correlated with high abundances of flatworms (Planariidae) and the mayfly *Fallceon*. Additional work is required to examine a wider variety of sites exposed to high metal levels to ascertain the metals tolerance of Planariidae and *Fallceon*. Possible nitrogen/organic matter effects on biotic condition were suggested by high scores on the Hilsenhoff Biotic Index (average pollution tolerance of invertebrates present), low numbers of Trichoptera (caddisfly) taxa, low abundances of insects overall, low abundances of grazers, and low abundances of Hydropsychid caddisflies, as well as high abundances of multivoltine taxa, tolerant taxa, and oligochaetes. Possible effects of TOC include lower taxonomic richness, lower

Shannon diversity, and lower numbers of EPT taxa. However, TOC also was associated with higher percentages of EPT and Odonata in the community due primarily to higher populations of *Hydropsyche*, *Caenis*, and Coenagrionids. Further evaluation of BMI community integrity with TOC is desirable.

4.4 Seasonal Variation of BMI Metrics

Data collected in this study documented a decline in BMI community integrity from June to September. The occurrence of indicator taxa *Simulium* (black flies) in June and Naididae (worms) in September is indicative of a change to a more pollution-tolerant fauna in September. A combination of factors was likely involved in this shift in community integrity, including seasonal increases in metal concentrations. In turn, the increase in metals concentrations from June to September was almost certainly due to the ramping up of irrigation during July, August, and September. The association of metal concentrations with this change in BMI community integrity may reflect anthropogenic influences, but could be associated with timing of the BMI lifecycle phases. That is, until natural temporal variation in BMI community structure and integrity is understood, effects of environmental variables, including those related to human activities cannot be measured with confidence. More extensive investigations are needed to examine the seasonal change in BMI metrics and the apparent relationship to metals, as well as other water quality factors, and irrigation patterns.

Several researchers (Osenberg *et al.*, 1994; Karr and Chu, 1999; Dorward-King *et al.*, 2001; Luoma *et al.*, 2001) proposed that the primary goal of a monitoring and assessment program is to distinguish anthropogenic-caused impacts from natural temporal variation. Without reference sites that are minimally influenced by anthropogenic stressors, obtaining this type of essential information in California's Central Valley will be difficult. Defining natural temporal and spatial variation in BMI communities of the Central Valley, especially in low gradient waterways, will be complicated because essentially all waterways and sites are influenced by anthropogenic activities. If natural temporal and spatial variation cannot be defined, separating anthropogenic impacts from natural variation will be a definite challenge.

4.5 Bioassessment Data Variability

When comparing BMI assemblages or metrics among sites it is desirable to have replicates at each site during every sampling event. This allows determination of within-site variability in BMI parameters and makes statistical comparisons possible among sites and at a site through time. Furthermore, if BMI bioassessment results are to be applied to decisions regarding impairment and remediation, it is essential that precision, representativeness, and repeatability of results be known. Reliability and credibility of results is critical. Many that use rapid bioassessment protocols (RBP) make the assumption that one sample (pooled transect samples) is an accurate, precise, and representative of BMI community integrity at that site. However, analysis of RBP replicates documented high variability—low precision (e.g., Barbour *et al.*, 1992; Resh, 1994; Hannaford and Resh, 1995). If within site variability of BMI data is high, comparisons among sites or at that site through time are invalid or highly suspect. Field sampling and laboratory sub-sampling appear to be the sources of greatest variability in BMI bioassessment results. Within site replication would enhance understanding of variability. Precision and repeatability of results should be reported in bioassessment studies. Data variability also affects the resolution/sensitivity of a procedure (ability to discern differences among sites and at a site through time). High variability reduces procedure sensitivity. Sensitivity (equivalent to detection limit in chemistry analyses) of procedure is crucial to the ability to distinguish impairment at sites. Low sensitivity of bioassessments, due to high data variability, has led to a conclusion that they are not reliable for detecting moderate to low impacts, especially related to chemical pollutants (Birge *et al.*, 1989; Waller *et al.*, 1996). Data variability and sensitivity of procedures are definite issues in bioassessment investigations (e.g., Hannaford and Resh, 1995; Carlisle and Clements, 1999).

Due to limited resources we were unable to perform site replicate samples in this study, and some sites were sampled only once. This limited data analysis in that we were unable to make statistical comparisons between specific sites. Thus, precision of these data is more suspect than if replicate samples were included. Nonetheless, we were able to analyze the entire dataset statistically for patterns rather than focus on differences between specific sites.

5. Recommendations

DeVlaming *et al.* (2004) set forth 13 recommendations concerning future use of BMI bioassessments in low gradient waterways of the Central Valley. Those recommendations are equally valid to this companion report, but are not replicated here. We encourage readers to visit the recommendations in that document. Below are additional recommendations specific to this report.

- Potential connections among metal concentrations, riparian zone quality, TOC, organic matter and BMI community integrity in the lower SJR watershed require further investigation.

- An apparent spring to fall decrease in BMI community health was observed in this study. More extensive investigations are needed examine the seasonal change in BMI metrics and the apparent relationship to metals, as well as other water quality factors, and irrigation patterns.

- A single site on a waterway or in a sub-basin is inadequate for characterizing biological condition. Future studies should include multiple sites on several waterways in the lower SJR watershed.

- The number of sites and frequency of site sampling was very limited in this study. While this study provided some baseline information on BMI community composition, the dataset was too small to reliably understand BMI community structures and health in the large lower SJR watershed. Further investigation is needed for a more complete understanding of BMI community structure and health.

- Ability to confidently recognize impacted/impaired sites/waterways and predict anthropogenic affects on aquatic systems depends on identification of 'reference' or least impacted sites. These sites should be sampled in different seasons and over several years to gain an understanding of natural temporal variation. Such information is crucial to distinguishing anthropogenic impacts from natural variation.

- We advise a consistent and continuous monitoring of physical, chemical, toxicological, and biological parameters (weight-of-evidence approach, see deVlaming *et al.*, 2004) at all waterway sites of interest. Without this full set of data, results of any one procedure are difficult to interpret. No one of these monitoring approaches provides all the information necessary for thorough interpretation or determining impacts/impairment, causes, and sources thereof.

Acknowledgments

This investigation was supported by the State Water Resources Control Board Surface Water Ambient Monitoring Program funds designated to the Central Valley Regional Water Quality Control Board. Tom Kimball and Jay Rowan played a major role in completing fieldwork for this project. Direction provided by Robert Holmes (contract manager) and Jay Rowan was invaluable.

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Table 1
Sampling site locations in the lower San Joaquin River watershed

Name	Code	Latitude	Longitude	Event June	Event Sept
Cosumnes River @ Michigan Bar Road	SAC 003	38.4997	121.0405		x
Lone Tree Creek @ Austin Road	SJC 503	37.8556	121.1847	x	x
Mtn. House Creek @ Byron Road	SJC 509	37.7856	121.5356	x	x
Ingram Creek @ River Road	STC 040	37.6003	121.2242	x	x
Del Puerto Creek @ Vineyard Road	STC 516	37.5214	121.1486	x	x
Harding Drain @ Carpenter Road	STC 501	37.4644	120.0303	x	
Orestimba Creek @ River Road	STC 019	37.4139	120.0142	x	x
Orestimba Creek @ Bell Road	STC 517	37.3458	121.0792	x	x
Mud Slough North: u/s San Luis Drain inflow	MER 536	37.2625	120.9056	x	
Salt Slough @ Lander Ave. (Hwy. 165)	MER 531	37.2486	120.8511	x	x
Bear Creek @ Bert Crane Road	MER 007	37.2556	120.6519	x	

Table 2
Taxa most common at the upstream Orestimba site (OC2), the Cosumnes River site (CR1), and the agricultural-dominated sites (the rest of the sites examined). Names of taxa common in one group of sites, but not among the 10 most common taxa of the other two groups, are shown in bold.

	Agriculture-dominated Sites		Upstream Orestimba Creek		Cosumnes River	
	Taxon	Percent of Community	Taxon	Percent of Community	Taxon	Percent of Community
1	**Naididae**	**0.233**	***Caenis***	**0.631**	Tanytarsini	0.214
2	**Tubificidae**	**0.218**	Chironomini	0.100	***Microcylloepus***	**0.194**
3	Orthocladiinae	0.145	***Hyalella***	**0.088**	*Simulium*	0.177
4	Planariidae	0.111	***Zoniagrion***	**0.043**	***Petrophila***	**0.051**
5	Tanytarsini	0.063	***Callibaetis***	**0.037**	Orthocladiinae	0.045
6	Chironomini	0.038	**Planorbidae**	**0.025**	Cyprididae	0.026
7	*Simulium*	0.031	**Tanypodinae**	**0.021**	**Hydropsychidae**	**0.026**
8	Corbiculacea	0.028	Planariidae	0.008	Prostoma	0.025
9	**Erpobdellidae**	**0.023**	Cyprididae	0.007	***Physa/Physella***	**0.024**
10	Prostoma	0.016	Corbiculacea	0.007	Planariidae	0.022

Table 3
Environmental parameters associated with site taxonomic clusters sampled in June 2001

Environmental Parameters	June Ag1 Mean	June Ag1 SD	June Ag1 Range	June Ag2 Mean	June Ag2 SD	June Ag2 Range	June Ag3 Mean	June Ag3 SD	June Ag3 Range	June upstream Orestimba
Width	12	5.6	8 - 18	3	1.3	2 - 4	5	5.1	2 - 11	13
Depth	43	14.3	28 - 56	26	6.0	22 - 33	34	18.1	21 - 55	44
Velocity	1	0.5	0 - 1	2	0.8	1 - 3	1	0.6	0 - 1	0
Temperature	26	3.0	23 - 29	26	1.2	25 - 28	25	3.4	22 - 28	31
SpC	995	793.1	93 - 1583	838	685.2	126 - 1493	775	446.5	487 - 1289	1498
pH	8	0.7	7 - 9	8	0.1	8 - 8	8	0.2	7 - 8	8
DO	9	1.8	7 - 11	10	1.0	9 - 11	7	2.8	4 - 10	10
Cr	3	1.4	1 - 4	7	5.5	1 - 10	12	17.9	1 - 33	
Cu	4	1.2	3 - 5	7	2.6	4 - 9	12	13.7	3 - 28	
Ni	6	2.9	3 - 8	11	7.1	3 - 15	21	27.6	3 - 53	
Pb	3	0.0	3 - 3	3	0.0	3 - 3	5	4.4	3 - 10	
Zn	8	4.4	5 - 13	10	4.0	7 - 15	26	29.5	8 - 60	
B	1	0.9	0 - 2	0	0.3	0 - 1	0	0.3	0 - 1	
Cl	169	153.4	3 - 305	72	65.0	3 - 132	82	38.8	56 - 127	50
Cd	1	0.0	1 - 1							
Arsenic	5	2.3	4 - 7							
Hardness	267	216.4	37 - 466	191	138.3	36 - 303	178	97.3	120 - 290	
Alkalinity	152	110.6	37 - 257	106	60.7	37 - 149	122	26.6	94 - 147	400
Total Dissolved Solids	708	580.0	85 - 1232	427	345.2	54 - 735	417	254.8	250 - 710	960
Total Suspended Solids	80	41.8	54 - 128	88	58.1	25 - 139	220	315.9	13 - 583	
Sodium	187	192.7	4 - 388	61	53.5	4 - 109	77	32.8	51 - 114	110
SO4	230	251.9	5 - 502	98	87.4	4 - 177	85	70.2	36 - 165	330
K	7	4.5	2 - 11	6	2.7	3 - 8	10	2.9	6 - 12	8
Nitrate	4	3.8	2 - 8	13	12.1	2 - 26	14	8.7	4 - 20	
Kjeldhal Nitrogen	1	0.1	1 - 1	1	0.3	1 - 1	3	2.0	2 - 5	
Total Phosphorus	0	0.1	0 - 0	0	0.0	0 - 0	1	0.7	0 - 2	
BOD5	3	1.2	2 - 4	3	0.6	2 - 3	5	1.5	4 - 7	1
BOD10	5	1.7	3 - 6	4	1.1	3 - 5	9	3.7	7 - 14	2
TOC	7	4.0	3 - 11	4	0.9	3 - 5	6	1.3	5 - 7	17
Mud	72	18.0	52 - 87	22	3.7	18 - 25	65	18.9	52 - 87	12
Sand	24	10.5	13 - 34	31	13.3	23 - 47	26	15.8	10 - 42	21
Gravel	2	3.8	0 - 7	38	28.9	5 - 57	8	9.3	0 - 18	52
Cobble	0	0.0	0 - 0	0	0.8	0 - 1	0	0.0	0 - 0	9
Boulder	0	0.0	0 - 0	0	0.0	0 - 0	1	1.9	0 - 3	0
Bedrock	2	4.2	0 - 7	8	13.5	0 - 23	0	0.0	0 - 0	0
Epifaunal Substrate	11	1.0	10 - 12	11	6.2	6 - 18	7	2.6	4 - 9	11
Pool Substrate	9	3.2	7 - 13	14	4.2	9 - 17	10	1.7	9 - 12	18
Sediment Deposition	9	2.5	6 - 11	12	3.6	9 - 16	5	2.1	3 - 7	18
Pool Variability	12	2.6	9 - 14	5	2.1	3 - 7	7	3.5	3 - 10	8
Channel Flow	15	1.2	14 - 16	13	2.3	12 - 16	13	3.1	10 - 16	3
Channel Alteration	15	4.9	9 - 18	12	5.3	6 - 16	6	3.2	2 - 8	11
Channel Sinuousity	15	2.6	13 - 18	11	4.4	8 - 16	2	0.6	1 - 2	7
Bank Stability	11	2.3	10 - 14	12	3.5	8 - 14	8	3.5	4 - 10	4
Vegetative Protection	12	2.9	9 - 14	12	3.2	10 - 16	6	2.0	4 - 8	8
Riparian Zone Width	14	7.0	6 - 19	9	4.0	5 - 13	3	2.3	2 - 6	14
Total Habitat Score	124	9.5	114 - 133	111	17.1	95 - 129	67	18.7	46 - 82	102

Table 4
BMI metrics associated with site taxonomic clusters sampled in June 2001

	June Ag1			June Ag2			June Ag3			June Upstream Orestimba		
Metrics	Mean	SD	Range	Mean	SD	Range	Mean	SD	Range	Mean	SD	Range
Taxonomic Richness	16	5.0	10 - 25	16	3.1	10 - 20	12	2.6	8 - 16	17	3.0	14 - 20
EPT Taxa	3	2.6	0 - 7	1	1.1	0 - 3	1	0.5	0 - 1	2	0.0	2 - 2
ETO Taxa	4	2.9	1 - 8	2	1.3	0 - 4	1	0.8	0 - 2	5	1.0	4 - 6
Ephemeroptera Taxa	2	1.8	0 - 5	1	0.7	0 - 2	1	0.5	0 - 1	2	0.0	2 - 2
Trichoptera Taxa	1	1.1	0 - 3	1	0.7	0 - 2	0	0.0	0 - 0	0	0.0	0 - 0
Coleoptera Taxa	0	0.5	0 - 1	0	0.0	0 - 0	0	0.0	0 - 0	0	0.0	0 - 0
EPT Index	3	2.7	0 - 8	2	2.1	0 - 6	2	3.5	0 - 8	71	12.2	58 - 82
Sensitive EPT Index (<4)	0	0.7	0 - 2	0	0.0	0 - 0	0	0.0	0 - 0	0	0.0	0 - 0
ETO Index	4	2.9	0 - 9	2	2.0	0 - 7	3	3.3	0 - 8	79	7.4	71 - 85
Shannon Diversity	2	0.3	1 - 2	2	0.3	1 - 2	1	0.5	0 - 2	1	0.3	1 - 2
Tolerance Value	7	0.8	5 - 7	7	1.2	5 - 9	8	1.9	5 - 10	7	0.3	7 - 8
Percent Intolerant Organisms	0	0.7	0 - 2	0	0.0	0 - 0	0	0.0	0 - 0	0	0.0	0 - 0
Percent Tolerant Organisms	29	15.5	8 - 48	47	27.8	10 - 95	67	33.5	16 - 98	27	18.3	16 - 48
Percent Hydropsychidae	1	2.3	0 - 7	1	1.7	0 - 5	0	0.0	0 - 0	0	0.0	0 - 0
Percent Baetidae	1	1.2	0 - 3	0	0.4	0 - 1	2	3.5	0 - 8	6	5.7	0 - 12
Percent Dominant Taxon	43	15.9	27 - 75	45	16.4	30 - 72	68	17.3	44 - 94	65	16.5	46 - 77
Percent Chiros	59	14.2	40 - 87	26	19.9	3 - 64	8	5.7	2 - 18	2	1.8	0 - 4
Percent Oligos	23	14.1	4 - 43	39	28.7	4 - 86	66	33.5	16 - 98	1	0.7	0 - 2
Percent Insects	64	14.1	47 - 90	42	25.4	5 - 82	12	8.0	2 - 23	81	5.9	74 - 86
Percent Coleoptera	1	0.8	0 - 2	0	0.0	0 - 0	0	0.0	0 - 0	0	0.0	0 - 0
Percent Collectors	60	24.1	17 - 90	67	18.8	38 - 88	78	25.6	40 - 100	84	5.7	78 - 90
Percent Filterers	32	23.3	4 - 76	21	17.9	4 - 53	2	2.6	0 - 8	0	0.0	0 - 0
Percent Grazers	1	1.3	0 - 4	2	1.3	0 - 4	0	0.2	0 - 1	6	4.3	2 - 10
Percent Predators	7	2.8	3 - 10	10	8.0	0 - 26	20	26.5	0 - 59	10	4.5	4 - 13
Percent Shredders	0	0.7	0 - 2	0	0.0	0 - 0	0	0.0	0 - 0	0	0.0	0 - 0
Percent Filter/Collect	92	2.5	87 - 95	87	8.0	72 - 99	80	26.6	40 - 100	85	5.9	78 - 90
Percent Multi-Voltine	96	2.6	91 - 99	98	1.8	95 - 100	100	0.5	99 - 100	86	9.1	76 - 92
T/C	3	3.2	0 - 10	3	6.0	0 - 17	1	0.6	0 - 2	0	0.3	0 - 1
Estimated Abundance	508	280.9	170 - 890	565	378.2	231 - 1400	1928	2401.7	360 - 7500	6367	1006.6	5300 - 7300

Table 5
Environmental parameters associated with site taxonomic clusters sampled in September 2001

Environmental Parameters	Sept Ag1 Mean	Sept Ag1 SD	Sept Ag1 Range	Sept Ag2 Mean	Sept Ag2 SD	Sept Ag2 Range	Sept Upstream Orestimba	Sept Cosumnes River
Width	3	0.8	2 - 3	7	5.5	1 - 14	8	15
Depth	36	3.8	34 - 39	45	29.7	17 - 73	37	10
Velocity	1	0.2	1 - 1	1	0.8	0 - 2	0	1
Temperature	28	1.8	27 - 30	22	3.8	17 - 25	27	28
SpC	916	422.1	617 - 1214	785	521.5	119 - 1393	1345	104
pH	9	0.1	8 - 9	8	0.3	7 - 8	8	9
DO	7	0.3	7 - 7	6	3.2	1 - 8	6	9
Cr	20	11.6	12 - 28	7	7.9	2 - 19		
Cu	16	7.9	11 - 22	9	4.5	5 - 15		
Ni	36	13.4	26 - 45	10	9.2	3 - 24		
Pb	6	4.7	3 - 9	3	1.3	3 - 5		
Zn	42	10.8	34 - 50	17	11.0	10 - 33		
B	1	0.3	0 - 1	0	0.2	0 - 1		
Cl	143	17.7	130 - 155	97	73.3	4 - 180		61
Cd	1	0.0	1 - 1	1	0.0	1 - 1		
Arsenic	4	1.0	3 - 4	3	2.3	1 - 6		
Hardness	315	7.1	310 - 320	177	122.9	53 - 285		
Alkalinity	148	10.6	140 - 155	111	55.7	49 - 165		
Total Dissolved Solids	833	335.9	595 - 1070	415	247.6	94 - 690		
Total Suspended Solids	875	1025.3	150 - 1600	126	102.6	58 - 275		0
Sodium	118	17.7	105 - 130	77	61.4	5 - 155		210
SO4	135	7.1	130 - 140	77	69.6	5 - 150		27
K	12	4.6	9 - 15	7	1.0	6 - 8		31
Nitrate	32	32.1	10 - 55	8	6.9	3 - 18		0
Kjeldhal Nitrogen	2	0.4	2 - 2	1	0.0	1 - 1		
Total Phosphorus	1	0.4	0 - 1	0	0.1	0 - 1		27
BOD5	3	0.6	2 - 3	4	2.9	1 - 8		
BOD10	6	2.8	4 - 8	7	6.1	2 - 15		
TOC	10	1.8	9 - 12	10	3.5	7 - 15		
Mud	45	14.1	35 - 55	43	24.2	20 - 67	13	0
Sand	36	1.2	35 - 37	31	3.2	27 - 33	40	12
Gravel	17	11.8	8 - 25	18	24.2	0 - 53	37	30
Cobble	3	3.5	0 - 5	1	1.7	0 - 3	8	47
Boulder	0	0.0	0 - 0	0	0.0	0 - 0	0	12
Bedrock	0	0.0	0 - 0	8	16.7	0 - 33	2	0
Epifaunal Substrate	6	0.0	6 - 6	12	3.6	8 - 15	13	7
Pool Substrate	13	1.4	12 - 14	12	3.3	9 - 16	18	14
Sediment Deposition	10	7.8	4 - 15	12	3.6	9 - 17	18	17
Pool Variability	4	1.4	3 - 5	10	2.2	8 - 13	10	10
Channel Flow	10	2.1	8 - 11	12	6.9	2 - 17	5	9
Channel Alteration	6	4.9	2 - 9	12	4.5	6 - 16	14	14
Channel Sinuousity	5	4.9	1 - 8	12	6.7	3 - 18	8	18
Bank Stability	9	7.1	4 - 14	10	1.4	8 - 11	8	17
Vegetative Protection	5	1.4	4 - 6	12	3.3	8 - 16	10	7
Riparian Zone Width	3	0.7	2 - 3	10	4.6	4 - 15	16	17
Total Habitat Score	69	31.8	46 - 91	114	28.9	72 - 135	120	130

Table 6
BMI metrics associated with site taxonomic clusters sampled in September 2001

	Sept Ag1			Sept Ag2			Sept Cosumnes River			Sept Upstream Orestimba		
Metrics	Mean	SD	Range	Mean	SD	Range	Mean	SD	Range	Mean	SD	Range
Taxonomic Richness	13	1.5	11 - 15	12	2.5	9 - 16	23	2.3	20 - 24	12	2.3	11 - 15
EPT Taxa	1	0.5	0 - 1	1	0.8	0 - 2	3	1.5	2 - 5	2	0.0	2 - 2
ETO Taxa	1	1.0	0 - 2	1	1.1	0 - 4	5	2.0	3 - 7	3	0.0	3 - 3
Ephemeroptera Taxa	1	0.5	0 - 1	0	0.5	0 - 1	1	0.6	1 - 2	2	0.0	2 - 2
Trichoptera Taxa	0	0.0	0 - 0	0	0.5	0 - 1	2	1.0	1 - 3	0	0.0	0 - 0
Coleoptera Taxa	0	0.0	0 - 0	0	0.0	0 - 0	2	1.2	1 - 3	0	0.0	0 - 0
EPT Index	0	0.2	0 - 0	1	2.1	0 - 7	6	2.7	3 - 8	63	18.1	42 - 74
Sensitive EPT Index (<4)	0	0.0	0 - 0	0	0.0	0 - 0	0	0.2	0 - 0	0	0.0	0 - 0
ETO Index	1	0.6	0 - 2	2	2.4	0 - 7	8	4.0	4 - 12	64	16.4	45 - 74
Shannon Diversity	1	0.3	1 - 2	1	0.5	0 - 2	2	0.3	2 - 3	1	0.2	1 - 1
Tolerance Value	6	0.8	5 - 7	7	0.9	6 - 9	5	0.4	5 - 5	7	0.2	7 - 7
Percent Intolerant Organisms	0	0.0	0 - 0	0	0.0	0 - 0	23	11.2	14 - 35	0	0.0	0 - 0
Percent Tolerant Organisms	36	16.2	18 - 58	72	25.5	27 - 100	7	4.7	2 - 11	13	0.8	12 - 13
Percent Hydropsychidae	0	0.0	0 - 0	1	2.1	0 - 7	3	1.7	1 - 4	0	0.0	0 - 0
Percent Baetidae	0	0.2	0 - 0	0	0.1	0 - 0	2	1.0	1 - 3	2	0.8	1 - 2
Percent Dominant Taxon	48	13.0	35 - 67	61	18.8	35 - 95	37	9.2	26 - 43	61	17.3	41 - 72
Percent Chiros	12	19.3	2 - 52	19	22.3	0 - 57	30	16.8	18 - 49	24	17.7	13 - 44
Percent Oligos	34	16.5	17 - 57	60	28.3	12 - 95	1	1.6	0 - 3	0	0.2	0 - 0
Percent Insects	13	19.2	3 - 52	22	23.4	1 - 59	82	6.2	76 - 89	88	1.7	87 - 90
Percent Coleoptera	0	0.0	0 - 0	0	0.0	0 - 0	22	10.1	14 - 33	0	0.0	0 - 0
Percent Collectors	55	16.3	32 - 73	80	21.6	15 - 98	36	9.9	28 - 47	91	1.7	89 - 92
Percent Filterers	1	1.7	0 - 4	7	5.4	0 - 14	42	23.4	15 - 56	2	1.6	0 - 3
Percent Grazers	0	0.2	0 - 0	1	2.2	0 - 8	14	11.0	7 - 27	0	0.2	0 - 0
Percent Predators	44	17.2	25 - 67	12	22.9	1 - 84	7	3.0	5 - 11	8	2.9	6 - 11
Percent Shredders	0	0.0	0 - 0	0	0.0	0 - 0	0	0.2	0 - 0	0	0.0	0 - 0
Percent Filter/Collect	56	17.2	33 - 75	87	22.7	15 - 98	79	13.8	63 - 88	92	2.8	89 - 94
Percent Multi-Voltine	100	0.5	99 - 100	98	2.4	93 - 100	72	12.9	57 - 81	97	1.0	96 - 98
T/C	1	0.3	1 - 1	2	3.0	0 - 9	13	15.5	3 - 31	0	0.1	0 - 0
Estimated Abundance	700	307.8	320 - 1100	498	298.1	150 - 1100	3363	3070.5	890 - 6800	4300	1253.0	3000 - 5500

Table 7
Taxa with relative abundance most strongly correlated with the NMS axes (|r| > 0.50)

Axis 1		**Axis 2**		**Axis 3**	
Taxon	r	Taxon	r	Taxon	r
Hyalella	0.868	Fallceon	0.670	Hydroptila	0.710
Caenis	0.862	Planariidae	0.669	Hydropsyche	0.594
Bezzia	0.806	**Naididae**	**-0.583**	Sperchon	0.564
Callibaetis	0.810			Orthocladiinae	0.554
Torrenticolis	0.762			**Tubificidae**	**-0.722**
Zonagrion	0.643				
Chironomini	0.572				
Planorbidae	0.570				
Tanypodinae	0.570				
Naididae	**-0.679**				

Table 8
Metrics most strongly correlated with the NMS axes (|r| > 0.50)

Axis 1		**Axis 2**		**Axis 3**	
Metric	r	Metric	r	Metric	r
ETO Index	0.878	None		Tax Rich	0.703
EPT Index	0.870			Trichoptera Taxa	0.701
Est. Abundance	0.776			% Grazers	0.604
Eph. Taxa	0.621			% Insects	0.586
ETO Taxa	0.581			% Hydropsychidae	0.550
% Tolerant	**-0.529**			**% Multivoltine**	**-0.573**
% Oligochaetes	**-0.632**			**% Tolerant**	**-0.582**
				% Oligochaetes	**-0.605**
				Tolerance Value	**-0.613**

Table 9
Environmental variables most strongly correlated with the NMS axes (|r| > 0.50)

Axis 1		**Axis 2**		**Axis 3**	
Variable	r	Variable	r	Variable	r
Width	0.607	**TOC**	**-0.590**	Natural Channel	0.591
Riparian Zone	0.577			Riparian Zone	0.551
Copper	**-0.602**			Habitat Score	0.672
Lead	**-0.550**			**Kjeld. Nitrogen**	**-0.627**
Zinc	**-0.547**			**BOD5**	**-0.695**
				BOD10	**-0.672**

Table 10
Pairwise Pearson product-moment correlations between environmental variables and BMI metrics. Correlations with r > 0.30 are highlighted light grey, correlations with r < -0.30 are highlighted dark grey.

	Correlation with				
Metric	Metals*	Nitrogen	BOD5	BOD10	TOC
Taxa Richness	-0.1017	-0.1909	-0.6291	-0.6035	-0.7275
EPT Taxa	-0.3014	-0.1639	-0.4352	-0.3833	-0.5320
ETO Taxa	-0.3700	-0.1225	-0.3172	-0.2462	-0.4150
Eph. Taxa	-0.1979	0.0667	-0.2167	-0.1585	-0.4828
Trichoptera Taxa	-0.3789	-0.3684	-0.4532	-0.4336	-0.4551
Coleoptera Taxa	-0.2252	-0.1965	-0.0252	-0.0678	0.1640
EPT Index	0.2493	-0.1492	-0.2530	-0.3052	-0.4170
Sensitive EPT	-0.2154	-0.1386	-0.2855	-0.2323	-0.3728
ETO Index	0.0929	-0.1410	-0.1798	-0.2168	-0.2842
Shannon Diversity	0.1333	-0.3459	-0.4483	-0.5171	-0.4453
Tolerance Value	-0.6528	0.2831	0.4981	0.4701	0.0933
Intolerant (%)	-0.2154	-0.1386	-0.2855	-0.2323	-0.3728
Tolerant (%)	-0.3905	0.2266	0.5895	0.5718	0.2374
Hydropsychidae (%)	-0.2643	-0.2662	-0.2380	-0.2567	0.0029
Baetidae (%)	0.5797	0.1174	-0.0199	-0.0769	-0.3514
Dom. Taxon (%)	-0.0896	0.4390	0.8162	0.8025	0.4731
Chironomidae (%)	-0.3373	-0.3893	-0.4347	-0.4378	-0.1215
Oligochaeta (%)	-0.3342	0.3387	0.5253	0.4903	0.1444
Insects (%)	-0.3706	-0.4110	-0.4909	-0.5068	-0.3030
Coleoptera (%)	-0.2252	-0.1965	-0.0252	-0.0678	0.1640
Planariidae (%)	0.9014	0.1034	-0.0688	-0.0187	0.0738
Collectors (%)	-0.3825	0.2955	0.1901	0.1469	0.0417
Filterers (%)	-0.4558	0.1034	-0.3366	-0.3520	-0.3381
Grazers (%)	-0.3076	-0.2885	-0.4385	-0.4652	-0.5049
Predators (%)	0.8415	0.1846	0.1328	0.1964	0.3024
Shredders (%)	-0.2154	-0.1386	-0.2855	-0.2323	-0.3728
Filter/Collectors (%)	-0.8440	-0.1579	-0.1014	-0.1642	-0.2691
Multivoltine (%)	0.4494	0.3235	0.2238	0.2281	0.0877
Est. Abundance	-0.1585	0.9042	0.0477	0.0503	-0.1519

* "Metals" indicates the summed concentrations of all metals correlated with BMI community composition (Cr, Ni, Cu, Zn, Pb)

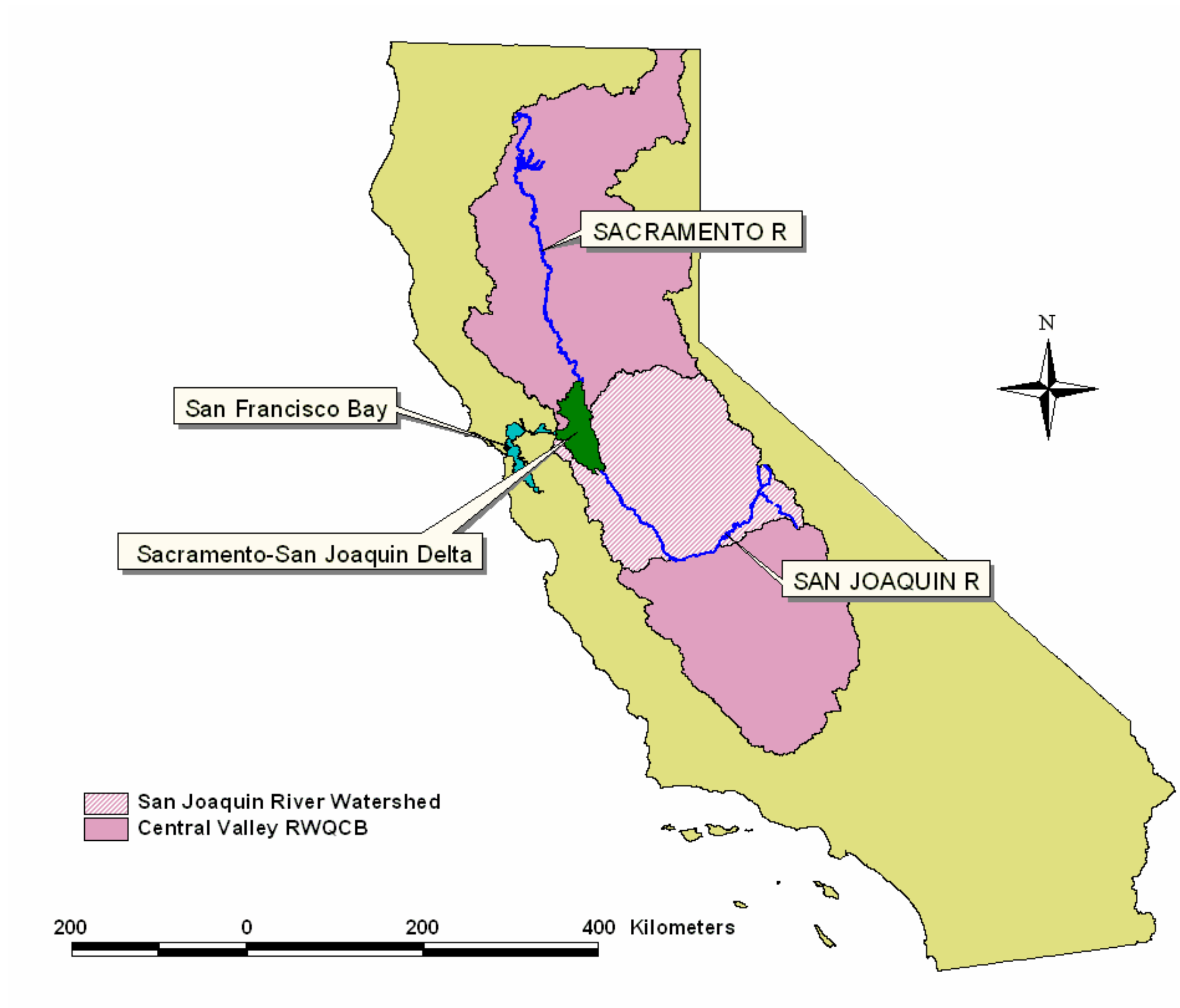

Figure 1. San Joaquin River watershed, Sacramento-San Joaquin Delta and San Francisco Bay.

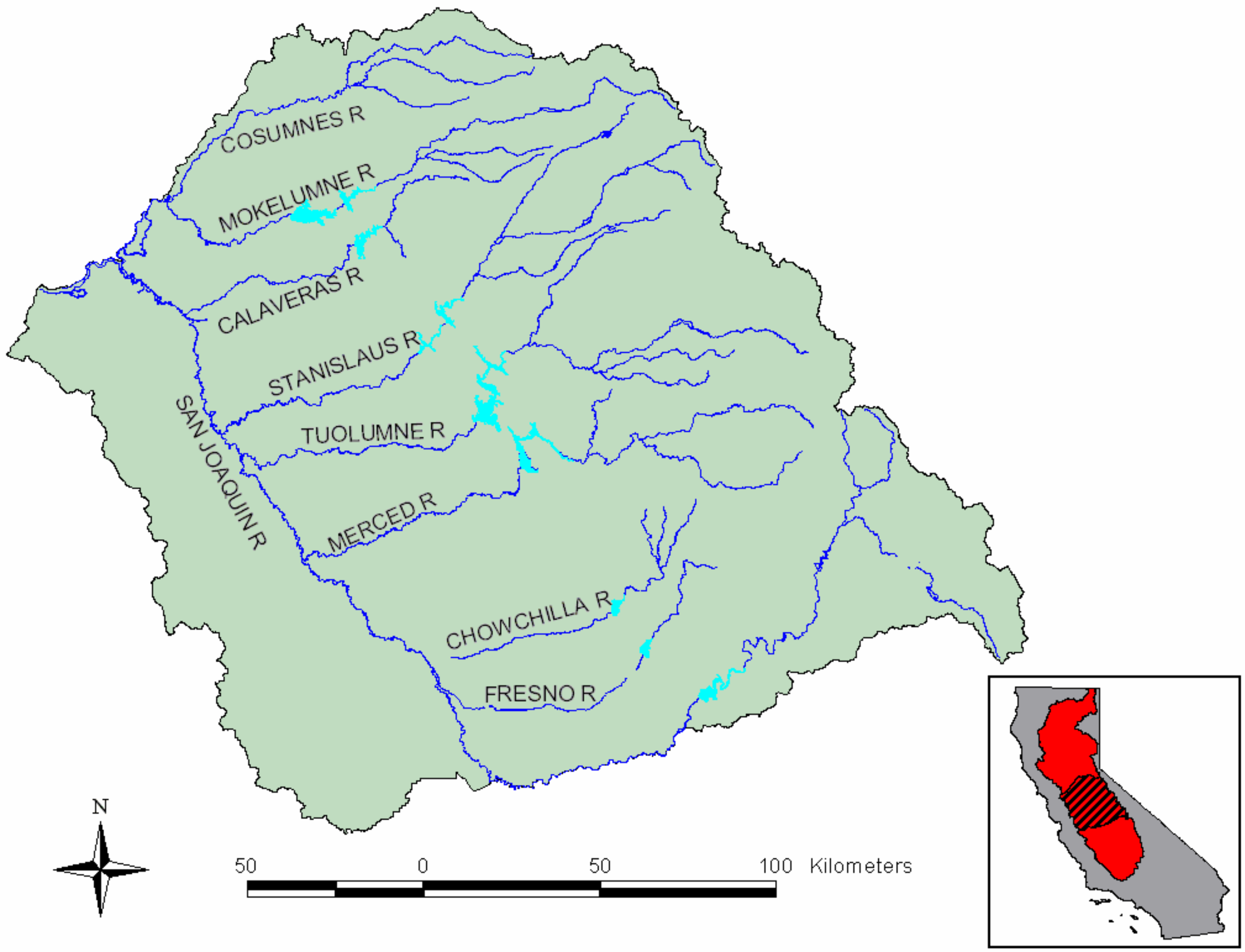

Figure 2. Major tributaries in the San Joaquin River watershed.

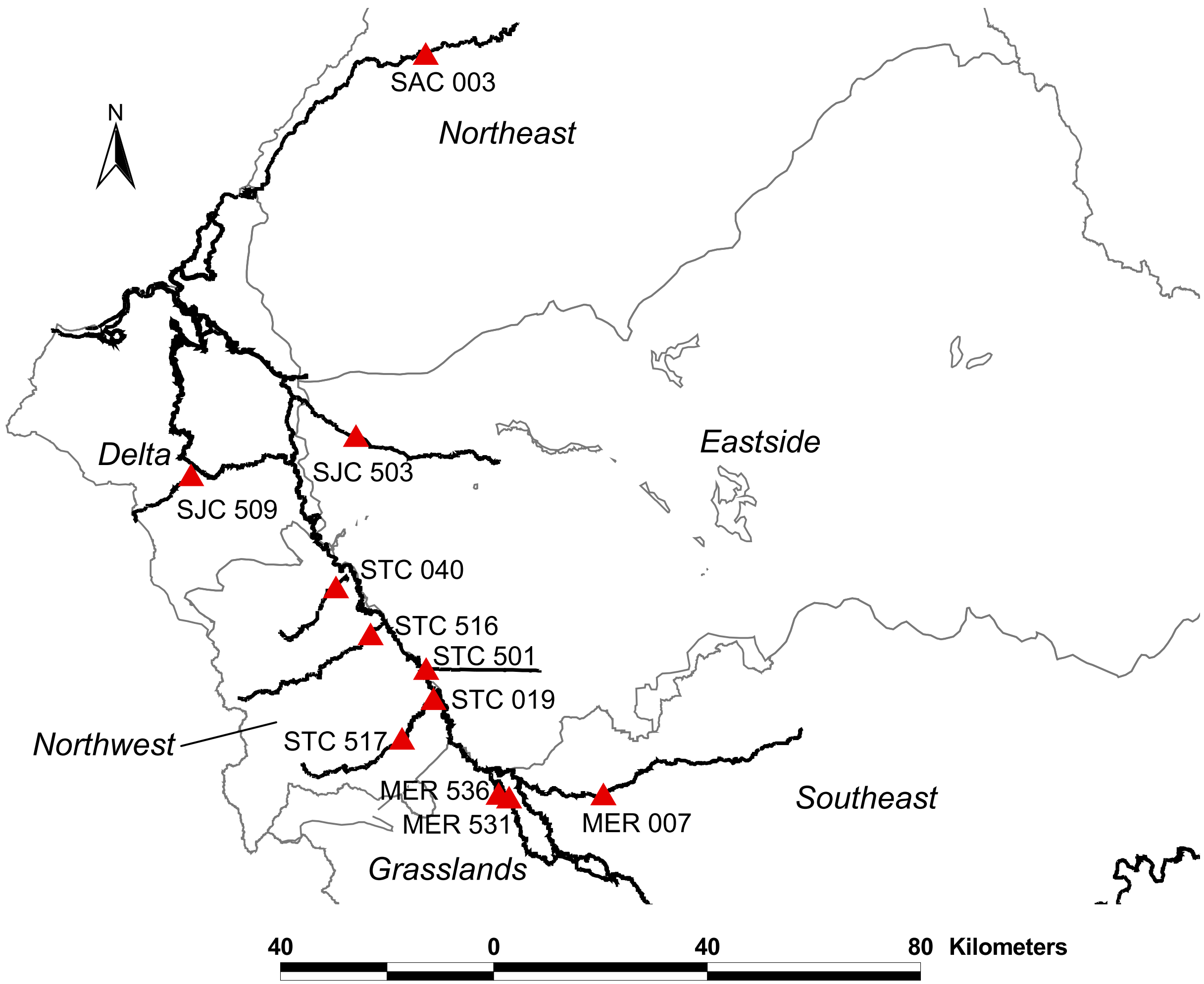

Figure 3. Sites in the San Joaquin River watershed examined by collection of BMI samples, water quality parameters, water column metals and nutrients data, and physical habitat parameters.

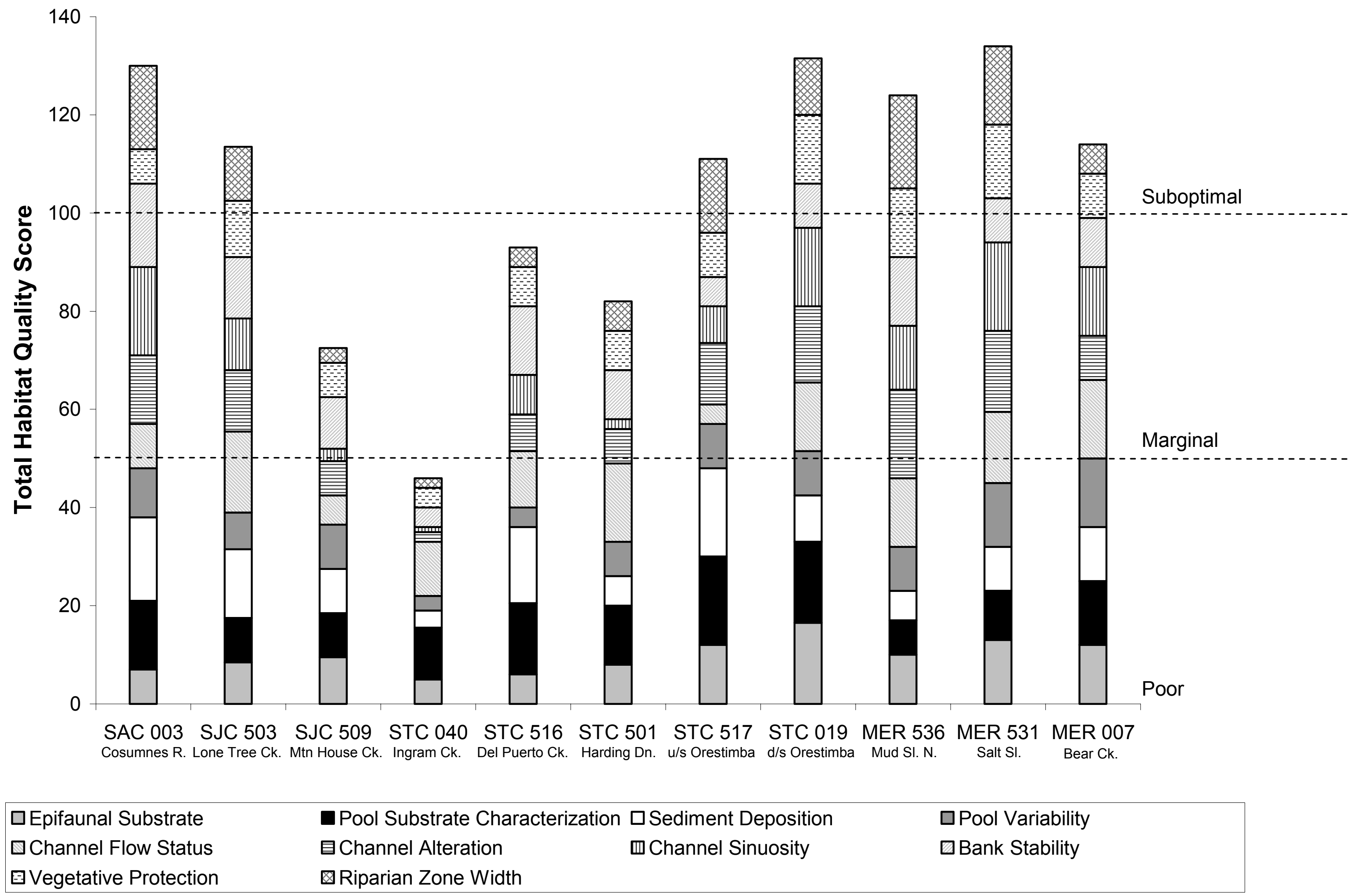

Figure 4. Physical habitat scores of sites in the lower San Joaquin River watershed. Scores are averages of June and September 2001 samples. Samples were taken from 11 different sites, consisting of 18 site visits.

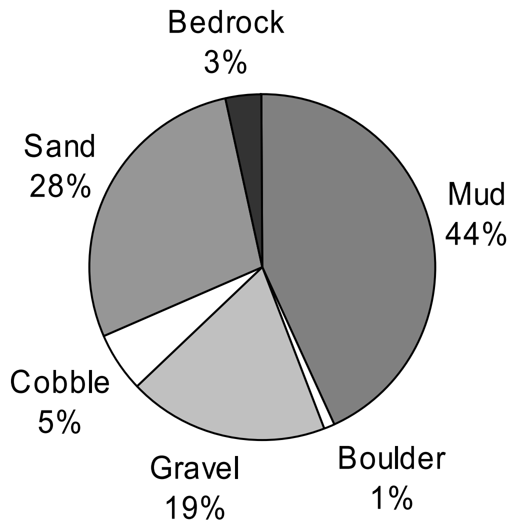

Figure 5. Average substrate composition at sites in the lower San Joaquin watershed. Average is based on all sites (n = 11) and all site visits (June and September 2001, 18 visits total). Cobble-sized substrates were actually composed of concrete riprap at all sites except at Orestimba Creek at Bell Road (STC 517) and the Cosumnes River at Michigan Bar (SAC 003).

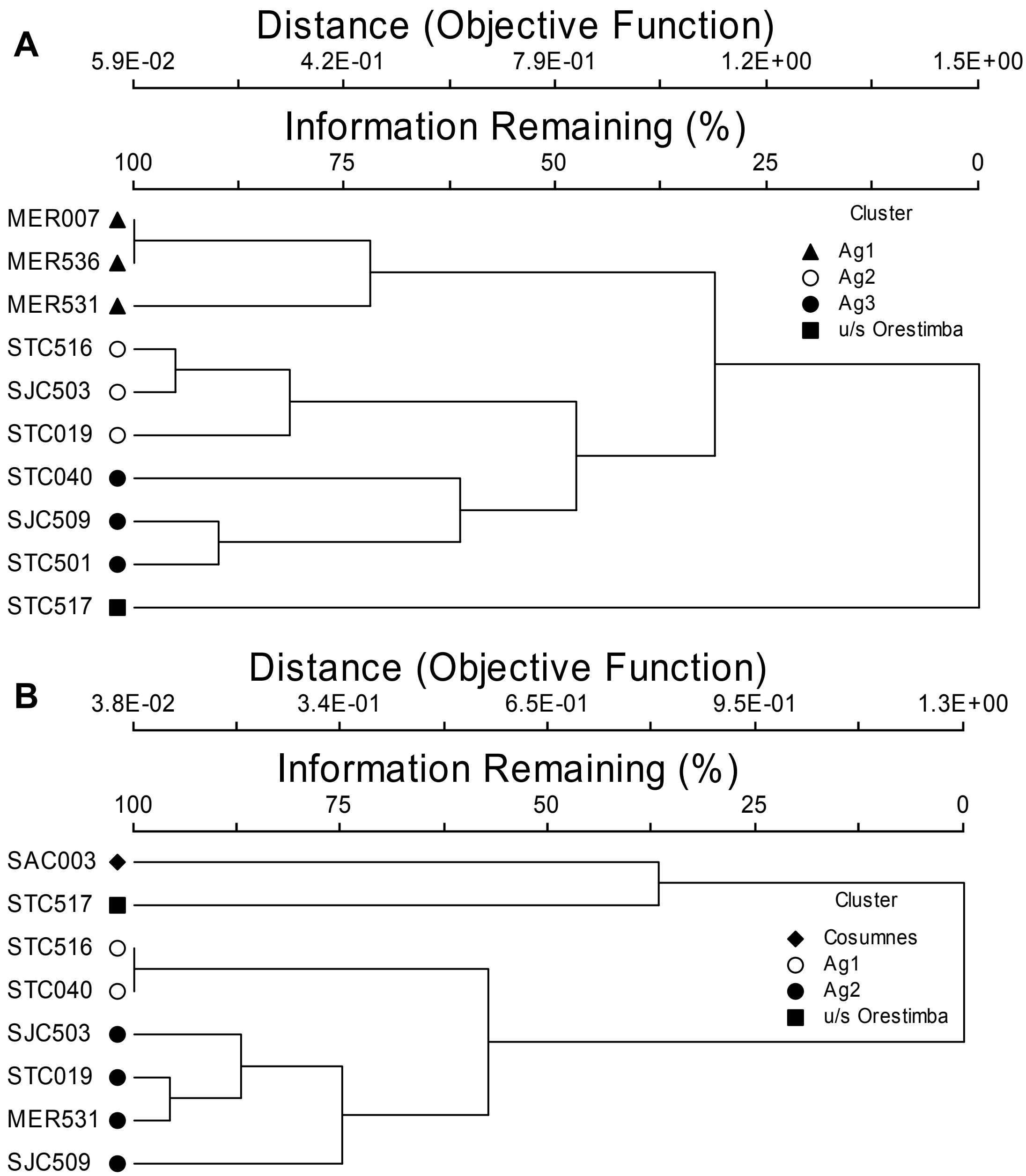

Figure 6. Cluster analyses of BMI samples grouping sites by similarity of BMI communities. (A) Samples collected in June 2001. (B) Samples collected in September 2001.

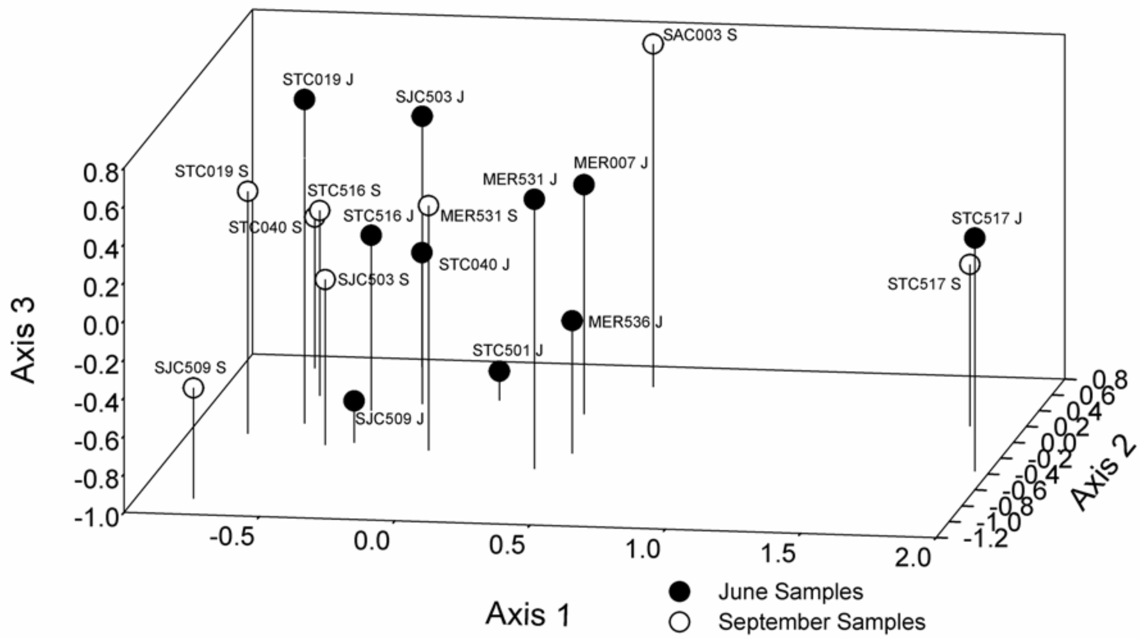

Figure 7. NMS ordination of taxa composition data at San Joaquin River watershed sites. Sites shown in close proximity on the NMS axes have similar BMI communities, while sites shown distant from each other have less similar BMI communities. Axis 1 summarized 62.5% of the variance in the dataset, while axis 2 summarized 10.5% of the variance, and axis 3 summarized 11.8% of the variance.

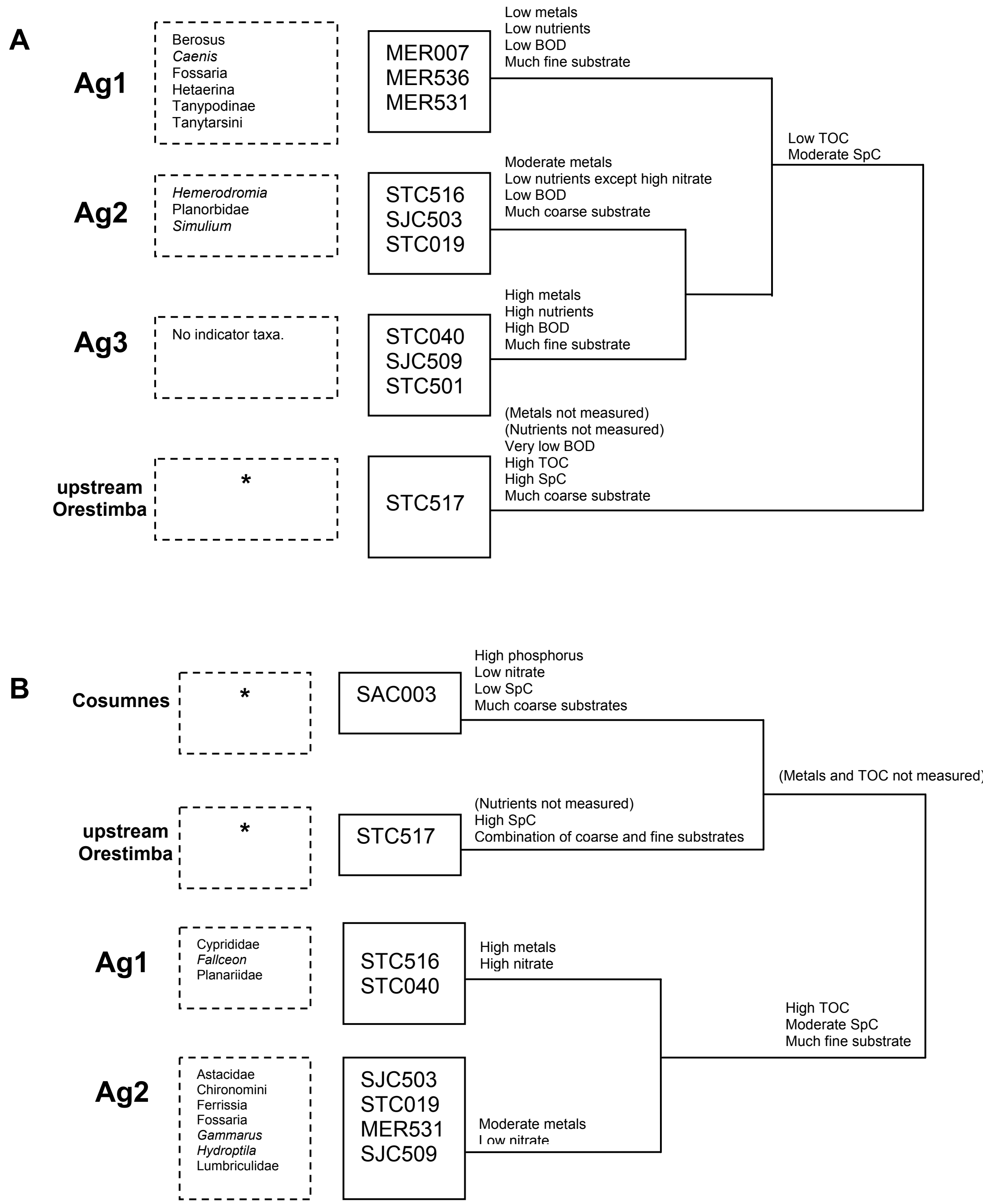

Figure 8. Site cluster dendrograms based on taxonomic similarities in samples collected in (A) June 2001 and (B) September 2001. Environmental parameters along dendrogram branches characterize those sites and appear to differ between adjacent clusters. Taxa indicated adjacent to each site cluster are those with higher indicator values for that cluster than for the adjacent cluster (difference in indicator values > 50). Sample sizes were too low to statistically evaluate differences in environmental parameters or indicator values.

*: Clusters consisting of one site could not be included in indicator species analyses.

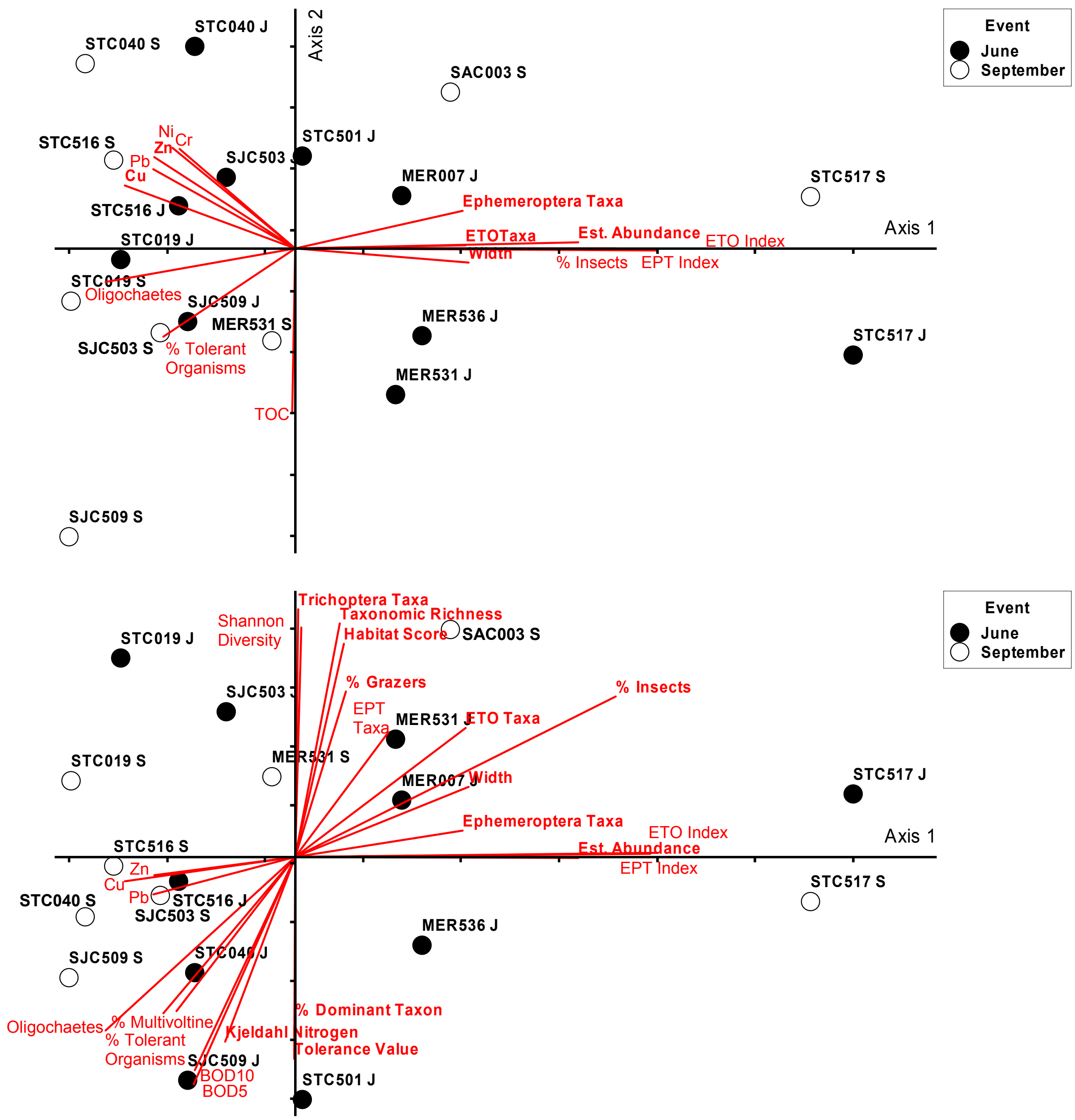

Figure 9. Non-metric multidimensional scaling (NMS) ordination of site data from the lower San Joaquin River watershed. Overlay illustrates environmental variable or BMI metrics correlated with the NMS axes at $r^2 > 0.30$. Taxa names represent the weighted average "center" of the distribution of each taxon. Value of environmental variable or BMI metric increases in the direction of the ray; length of ray reflects the strength of the correlation. Rays parallel to an axis are highly correlated with that axis. Rays perpendicular to an axis indicate little association with that axis.

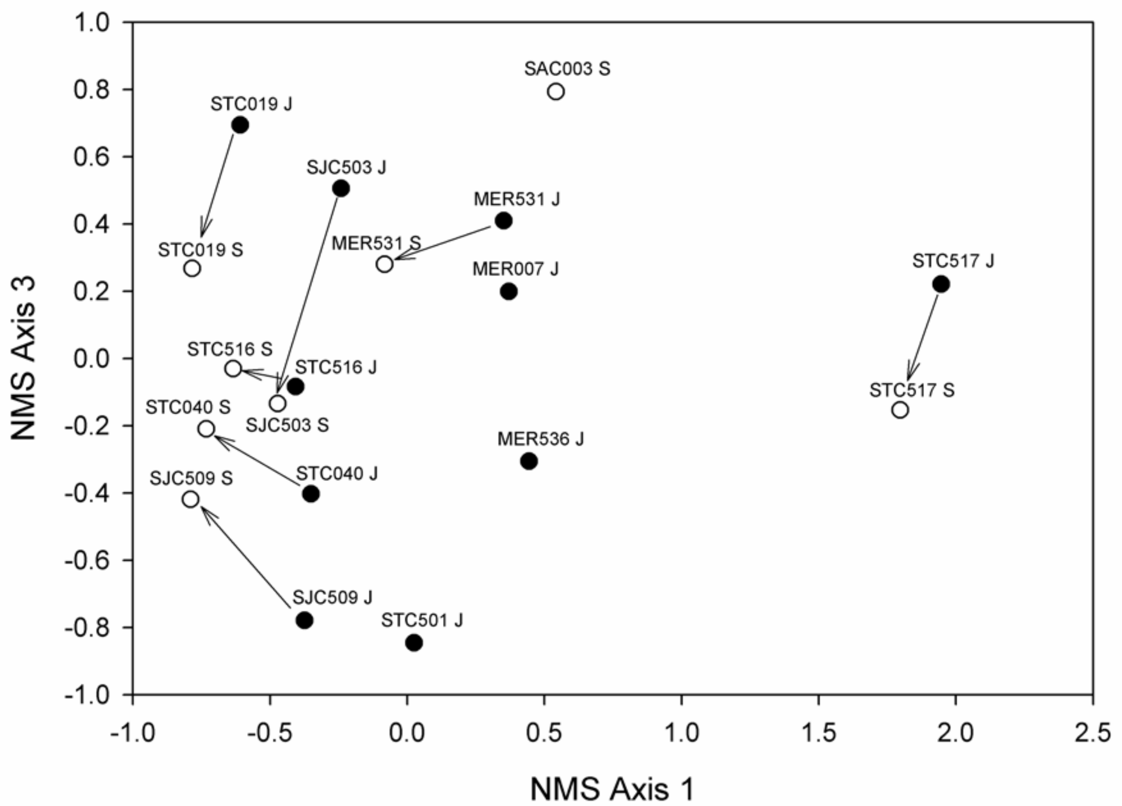

Figure 10. Among sites and seasonal variation in species composition in waterways of the San Joaquin River watershed. Filled symbols represent sites sampled during June; open symbols represent sites sampled during September. Vectors connect June and September samples collected at the same site.